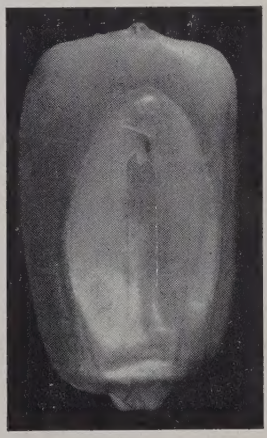
PERICARP INJURIES IN SEED CORN

Prevalence in Dent Corn and Relation to Seedling Blights

By Benjamin Koehler



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PERICARP INJURIES IN SEED CORN:

Prevalence in Dent Corn and Relation to Seedling Blights

By Benjamin Koehler, Professor of Plant Pathology

MOST SEED PROCESSORS AND PRODUCERS seem to be unaware of the large amount of pericarp damage in their seed samples, and of the potential hazard to corn production. Corn is one of the crops that are particularly susceptible to seedling blight when the pericarp or seed coat is broken and not protected by a fungicide. In order to protect seed corn from infection by soil organisms causing seedling blight, practically all seed processors have adopted the practice of treating their seed with a protective fungicide. However, the control resulting from seed treatment has not been completely effective, and a high prevalence of pericarp injury in the seed could still mean an appreciable loss from seedling blight.

The occurrence of pericarp injuries in seed corn and their importance in respect to stand, yield, and resistance to seedling blight in dent corn were studied over a period of years. Considerable attention was given in these studies to seed treatment and the degree to which protective fungicides can limit the harmful effects of pericarp injury. Many samples of commercial seed from different sources were examined for the extent and types of pericarp damage. Seed differing in maturity, moisture content, and genetic constitution were tested to determine the degree to which these and other factors influence the susceptibility of the seed to pericarp injury from mechanical hazards, and experiments in the field and cold tests were conducted to distinguish between the various types of injury, according to their locations on the kernel, in their effects on stand and yield in infested soil.

Resistance in inbreds was studied in relation to the pericarp condition of the seed, and experiments were conducted to determine if there is any correlation between resistance to seedling blight caused by different soil fungi. Several of these inbreds were then tested for their contribution to resistance or susceptibility in single crosses.

Seed-corn processing plants were not investigated to determine where and how injuries occur. To a large extent, each plant has developed its own system of handling the seed, and as a result the problems of preventing pericarp injury differ. A limited study on the occurrence of injuries in processing has been reported by Wortman and Rinke (46).

HISTORICAL REVIEW

Meyers (35) as early as 1922 observed the importance of the pericarp in protecting seed corn against seedling blight infection. He inoculated sound and pericarp-injured seed with an unidentified species of Penicillium, planted them in field plots, and obtained striking reductions in stand and yield when the seed was injured. There have been earlier reports (2) on the detrimental effects of pericarp injuries on yield, but these did not mention any relationship between the injuries and seedling diseases.

When open-pollinated corn was in general use, various experiments were reported in which yield comparisons were made between seed from smooth ears and seed from ears with rough indentations. Montgomery (36), Cunningham (4), Manns and Adams (34), Holbert *et al.* (11), Edgerton and Kidder (6), and others found that seed from smooth ears yielded better than seed from rough ones. None of these investigators reported differences in pericarp injuries between the two ear types, but the excellent pictures published by Holbert *et al.* in 1924 (11, Figs. 65-70) clearly show numerous kernels in rough ears with the pericarp severely damaged at the crown.

In 1930, Koehler and Holbert (29) pointed out that rough ears are particularly subject to pericarp breakage, and that pericarp injuries and broken tip caps facilitate seed infection by soil organisms. Subsequent experiments by the writer in 1933-1936 revealed that differences in field performance between rough and smooth ears were probably due mainly, but not entirely, to differences in the condition of the pericarp.

A project on the pathological significance of pericarp injuries in seed corn was begun by the writer in 1933. Research on this problem and the types of soil organism involved had been very limited up to that time. Brief reports were published in 1935 (26, 27), 1936 (22), 1938 (30), 1948 (23), and 1954 (28). Published results by other investigators are mentioned throughout this bulletin where they apply to the experiments reported.

GENERAL MATERIALS AND METHODS

Seed samples

Most commercial samples of seed used in determining the frequency and types of pericarp injuries were obtained from the Illinois Crop Improvement Association. Some were also taken from remnants of seed used in the Illinois Station's annual tests of commercial hybrids. Seed of inbreds and single crosses for studying resistance in relation to pericarp injury were supplied by the Plant Breeding Division of the Agronomy Department and by the Illinois Seed Producers Association.

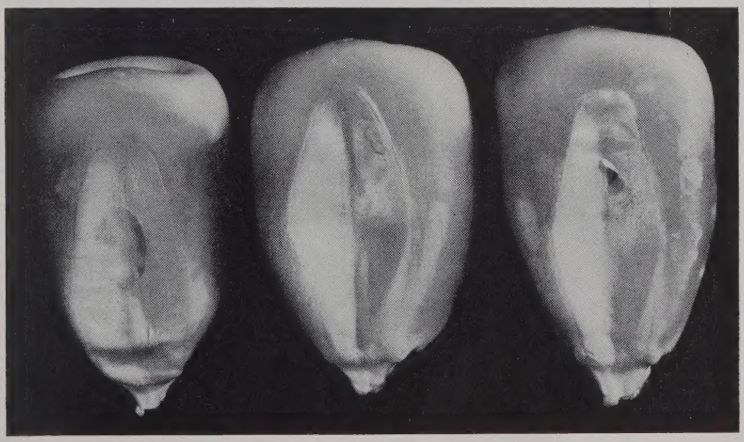
For some experiments it was desired to have seed from open-pedigree hybrids, free of pericarp damage. Arrangements with various producers permitted the writer to pick the ears by hand directly from a seed-production field. These ears were rack-dried and handled carefully at all times to prevent pericarp damage.

Injury classes. Eight classes of pericarp injury were usually recognized:

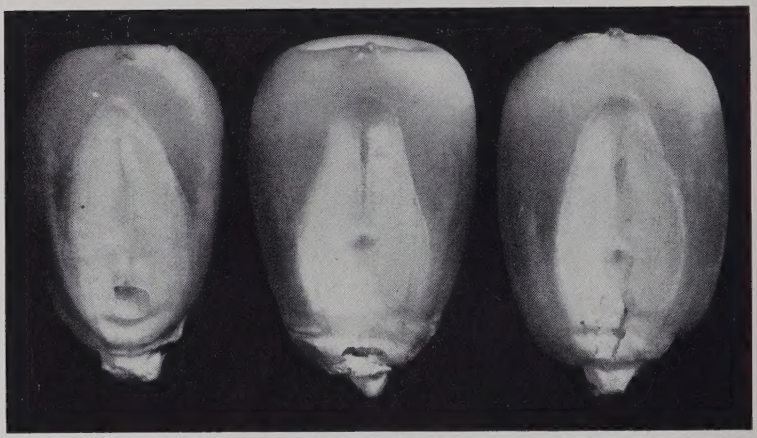
1. Severe crown injury — one-fourth or more of the crown pericarp missing.

2. Slight crown injury — crown pericarp cracked or less than one-fourth missing.

3. Injury over the plumule — any break on the face of the germ area above the central node and not limited to the edge of the germ



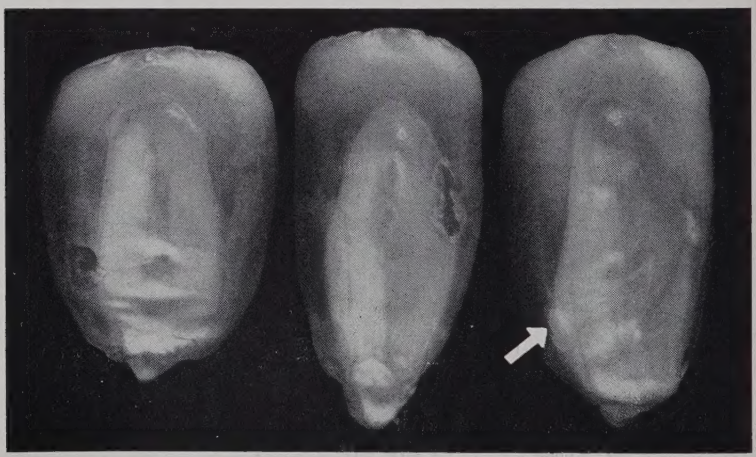
Pericarp injury over the plumule caused by mechanical operations. (Fig. 1)



Pericarp injury over the radicle. Note that on two kernels the injury extends to the lower margin of the germ area. Such injuries were classified as injuries over the radicle, rather than injury at the margin of the germ. (Fig. 2)

area (Fig. 1). (The central node often appears slightly elevated in the center of the germ area as shown in Fig. 2.)

4. Injury over the radicle — injuries below the central node, including the lowest margin of the germ area (Fig. 2).



Pericarp injury at the margin of the germ area. These, as other injury classes, varied in size, sometimes consisting of a small crack, as is shown on the right. (Fig. 3)

5. Injury around the edge of the germ — injury anywhere on the entire periphery of the germ area except the lowest part directly over the radicle (Fig. 3).

6. Other pericarp injuries — injuries on the side or back of the kernels, including cracks which often occur when the kernels are wrinkled near the tip. Some kernels showed deep fractures extending through the horny endosperm.

Other pericarp injuries. This category included all pericarp injuries not specifically named in other classes. They occurred primarily on the edges and backs of the kernels and frequently involved the exposure of only horny endosperm. (Fig. 4)

Tip cap broken off is not, strictly speaking, a pericarp injury, but it is included because it is related and predisposes the seed to invasion by soil fungi. Cracked kernels were recorded only in the data presented in Table 5. Such kernels were rare in commercial seed samples, and therefore this classification was not ordinarily used in examining them.

Examination and sorting. A group of specimens for each injury class was prepared for the guidance of assistants who did the sorting. Until 1951 seeds were examined with a 9x binocular microscope or a 7x tripod magnifying glass. In that year, however, a staining technique was adapted, similar to one used by Huelsen and Brown (21), which made it possible to detect more than twice as many injuries of most

classes. Subsequently all seeds were stained by the following procedure before examination, and a magnifier was used only for questionable cases.

A sample of 200 kernels in a wide-mouthed bottle was covered with a 0.1-percent solution of Fast Green FCF in water and stirred intermittently for 30 seconds. The seed was then washed in several changes of water and spread on absorbent paper to air dry.

The stain adhered only to the broken places in the pericarp and to the tip where the kernel had been attached to the pedicel. It was determined that this stain had no biological effect, so the seed could be planted for seedling-blight comparison tests.

Each injury was recorded, and as kernels frequently had more than one type, the total injuries in a sample sometimes exceeded 100 percent. For this reason the percent of sound kernels is also given in the tables.

For some experiments certain types of injury were made by cutting off or into the pericarp with a sharp knife. When removing a part of the pericarp, an effort was made to remove as little as possible of the underlying tissue.

Pretesting for fungicide or infection. Untreated seed was desired for some tests. Until 1951 commercial samples of seed for those tests were tested for the presence of a seed-treating fungicide. But after the staining technique was adopted, this testing was discontinued because originally treated and untreated seed showed no appreciable difference in results in the cold tests. Evidently so little fungicidal residue remained on the seed after staining and washing, that it was ineffective.

When sound seed that had not been exposed to mechanical damage was needed, hand-picked ears were tested for germination in a disinfested sand bench at 70°-75° F. Ears having 100-percent strong germination in a test of 10 representative kernels were then retested by surface-sterilizing representative kernels and plating them on potato dextrose agar medium to eliminate seed of ears with internal fungus infections. Selected ears were then shelled (by hand, unless otherwise noted). The seed was soaked with agitation for 10 minutes in a 0.28-percent solution of sodium hypochlorite to eliminate the possibility of infection from surface-borne organisms after planting.

Seed treatment. A protective fungicide was applied to the seed for some tests. Unless otherwise mentioned, the chemical used was thiram under the trade name, Arasan SF-X. The various rates of application are given in the appropriate tables.

Greenhouse and cold tests

Seedling-blight comparison tests at controlled temperatures were made in a walk-in refrigerator and a greenhouse usually kept at 70°-75° F. In the "cold tests," the trays were kept at 50° F. for a period of 5 to 20 days before placing them in the greenhouse. Seeds were planted in wooden trays 3½ inches high that had been filled with 1¾ inches of soil, then covered with an additional 1¼ inches of soil. Four or more replications of thirty seeds each were used in each experiment. The trays were stacked to avoid water loss during the cold period. Except for experiments where specific soil moistures were desired, the moisture content of the soil was adjusted to the damp margin of its favorable working range and no additional moisture was added until the trays were removed to the greenhouse.

For experiments with naturally infested soil, dark silt loam prairie soil was taken from a field that had just previously been cropped to corn. Hooker (12) found seedling-blight damage most pronounced in soil that had previously been planted to oats or corn, least when it had been meadow. However he found considerable variation between samples from two farms with similar rotations. Soils used in the cold tests varied in their ability to infect the seed, but some control could be exercised over the severity of the disease by varying the length of time in the refrigerated chamber. Some soils required a day or two longer than others.

For inoculation with pure cultures, plantings were made in Torpedo sand (coarse builder's sand) that had been steam-sterilized or treated with formaldehyde. Results were similar to those obtained with soil, but sand was preferable for these plantings as steam-sterilized soil was usually toxic to seedlings.

Results in the cold tests were recorded by several methods. Data were taken after the third leaf was well-developed in the check rows — the rows most nearly free from disease — and before the fourth leaf emerged. Stand was recorded and vigor estimated by one of the following measures: (a) height of seedlings above ground to the tallest leaf, (b) green weight of seedlings per replicate, and (c) growth index, derived by giving a value of 4 for a plant with 3 leaves, 3 for 2 leaves, 2 for 1 leaf, and 1 for a coleoptile that had emerged but not opened to expose the first leaf (Fig. 14). Totals were then adjusted to give a value of 100 for a perfect stand of plants with 3 leaves. Comparative values for these three methods are given in Fig. 11.

Field tests

All field tests were made on the Agronomy South Farm at Urbana. Soil was a dark silt loam prairie soil of good, but not exceptional, fertility in a rotation that included a legume one year in four. Plots were usually 2 × 10 hills in size, spaced 39.6 inches (4,000 hills per acre) with 3 kernels per hill. Replications varied from 8 to 12, depending on the experiment. The time of planting was consistent with the usual agricultural practice in the area. Yield as well as stand data were obtained.

Statistical interpretation

The significance of results was measured by the analysis of variance. Unless otherwise indicated, the least significant difference (L.S.D.) given in the tables is based on the 5-percent level. Where a more precise interpretation seemed advisable, percentage figures were converted to angles (arc sin times square root of the percentage), a figure of 90 being equivalent to 100 percent. However, the figures for angles and percents are not related by a linear function, as can be seen in Tables 14, 17, and 20. Correlation coefficients were calculated for some data.

OCCURRENCE OF PERICARP INJURIES

Prevalence of injuries in commercial seed

Commercial samples of seed corn were examined and separated into seven injury classes, beginning with the 1942 crop. Seeds were examined with magnifiers until after 1951 when the staining technique described on page 10 was used for examinations. In 1951 samples were examined before and after staining and a considerable number of injuries were detected that had not been noticeable before staining (Table 1). Samples were reduced to size with a Boerner divider and 200 kernels were used for each analysis. The number of samples varied from year to year, as is shown in Table 1.

Yearly variations. Two classes of pericarp injuries — severe crown injury and tip cap broken off — offered a good index of comparison for the entire period since they are easy to detect and had been revealed in the same percentages both stained and unstained (1951, Table 1). Severe crown injury varied from 1.5 percent in 1945 to 8.3 percent in 1952. Tip cap broken off varied from 2.8 percent in 1947 to 12.6 percent in 1943. Part of this variation may be accounted for by the

Table 1. — Prevalence and Types of Pericarp Injury Found in Commercial Seed Corn
(Samples of commercial hybrids obtained from Illinois growers, 1942-1954. Beginning with 1951 crop, all samples were stained with a solution of Fast Green FCF before examination.)

Crop year	Number of samples examined	Part of samples averaged	Seed with sound pericarps	Pericarp injury classes						Tip cap broken off
				Severe crown injury	Slight crown injury	Injury over plumule	Injury over radicle	Around edge of germ	Other pericarp injuries	
			perct.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
				Unstained seed						
1942	36	all	64.5	1.6	1.0	11.3	13.9	4.9	1.8	5.3
1943	24	all	49.6	3.6	4.0	10.9	13.0	7.0	6.4	12.6
1944	28	all	66.4	3.2	5.4	6.1	4.8	6.3	.9	6.9
1945	58	all	67.3	1.5	2.8	4.3	6.7	4.5	1.6	11.3
1946	46	all	59.1	3.1	2.7	6.1	20.5	4.0	1.5	3.2
1947	46	all	58.5	3.7	2.9	8.4	21.4	2.1	1.6	2.8
1951	42	all	55.7	4.3	3.5	4.0	13.0	14.2	9.1	7.3
				Stained seed						
1951	42	all	20.2	4.3	9.1	6.2	23.2	31.2	17.7	7.4
		10 best	44.1	3.6	7.4	5.4	9.4	17.0	13.3	4.8
		10 poorest	2.6	4.6	10.0	7.4	39.8	41.0	19.2	7.9
1952	48	all	23.2	8.3	16.7	14.2	36.5	21.0	15.4	8.5
		10 best	46.2	5.0	8.8	11.0	16.6	14.3	9.4	4.4
		10 poorest	2.7	13.5	23.4	17.7	64.4	32.4	29.4	13.9
1953	120	all	20.7	5.5	12.2	19.8	45.4	32.8	19.5	4.0
		10 best	59.4	3.8	6.8	9.2	13.9	10.8	5.4	2.5
		10 poorest	.2	9.4	21.0	30.6	76.7	35.1	47.9	9.4
1954	58	all	22.6	4.3	22.3	15.6	35.9	33.3	17.3	3.3
		10 best	55.6	3.4	15.1	7.6	11.6	12.0	5.9	1.4
		10 poorest	2.3	6.0	30.0	19.3	59.0	48.6	23.2	4.0

Table 2. — Prevalence and Types of Pericarp Injury in Relation to Grade Size

(Graded samples of commercial hybrids examined in three crop years)

Crop year	Number of samples	Grade	Size	Kernels with sound pericarps	Pericarp injury classes					Tip cap broken off
					Severe crown injury	Slight crown injury	Injury over plumule	Injury over radicle	Other pericarp injuries	
				perct.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
				Unstained seed						
1942	6	Flat	Small	68.1	1.8	1.2	9.3	15.3	.9	4.6
	6	Flat	Medium	64.1	1.6	1.3	8.1	17.7	1.6	6.1
	6	Flat	Large	61.7	2.0	1.3	9.8	16.3	1.5	7.2
	6	Round	Small	64.4	.7	1.1	10.5	14.9	1.3	7.1
	6	Round	Medium	64.4	1.2	.3	9.2	15.9	1.8	7.2
	6	Round	Large	64.1	1.8	.9	9.4	13.9	3.7	6.2
		L.S.D. (5-percent level)		N.S.[a]	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
1943	4	Flat	Small	58.6	2.4	3.9	7.9	13.9	6.4	7.0
	4	Flat	Medium	56.0	4.2	5.0	6.4	13.0	6.6	8.8
	4	Flat	Large	49.5	5.3	7.8	32.0	13.4	5.6	9.1
	4	Round	Small	48.2	2.6	1.8	12.4	15.2	5.5	14.2
	4	Round	Medium	41.7	3.4	2.0	12.6	17.6	6.9	15.7
	4	Round	Large	43.0	3.6	3.6	10.2	11.1	7.4	21.0
		L.S.D. (5-percent level)		8.6	1.8	3.8	N.S.	N.S.	N.S.	6.1
				Stained seed						
1953	14	Flat	Small	27.8	3.5	6.8	11.8	38.5	17.1	2.4
	14	Flat	Medium	28.3	5.4	8.9	15.6	36.5	15.1	2.8
	14	Flat	Large	25.3	5.7	10.6	20.5	41.4	15.6	3.0
	14	Round	Small	26.0	2.8	5.2	20.1	41.0	18.3	3.0
	14	Round	Medium	24.0	3.3	5.4	22.4	44.5	20.3	3.5
	14	Round	Large	23.8	3.5	7.5	25.2	44.9	21.8	4.8
		L.S.D. (5-percent level)		N.S.	.8	1.7	4.2	N.S.	3.7	1.1

[a] Not significant.

small number of samples analyzed, but the range of difference indicates that the occurrence of pericarp injuries may vary widely from year to year.

Variations between samples were found in each year that seed was examined for injuries. This agrees with the results of Tatum (43) who noted that ". . . the type and degree of injury vary with the different producers. Some consistently produce seed that is relatively free from injury while others rather consistently injure a high percent of the kernels." Average percentages of sound and damaged kernels for the 10 best and 10 poorest samples are given for the last four years of data in Table 1. In 1952, the 10 best samples had 2.9 percent of the kernels injured at the crown; the 10 poorest had 17.6 percent. That there are such wide differences suggests that much improvement over present methods of processing seed is possible.

Variations between grades. Samples of six selected grade sizes of the same hybrid were obtained from each of a number of seed processors for three years. There was a strong trend for the percentage of crown injury (severe and slight) to increase as the size of kernel increased. This type of injury also occurred more frequently in flats than in rounds. Injury over the plumule in 1953 also increased significantly as size of kernel increased, but rounds had more injuries of this type than flats. The same relationship held for tip cap broken off, with significant differences in two years (Table 2). Sound kernels, as might be expected, increased as size of kernels decreased, significantly so in one year. In two years there were more sound kernels among the flats than among the rounds, and this was significant in one year. The results of this three-year test, representing 14 growers in 1953, agree with more limited data reported by Wortman and Rinke (46); that is, the most crown injury occurred in flats; the most injury on the face of the germ in rounds; and the most total injury in rounds.

Effect of maturity and hybrid

Spontaneous pericarp injuries. Three double crosses were tested in 1955 for spontaneous cracking of the pericarp in relation to maturity and hybrid. These were made up by using seed of inbreds Ind. WF9 male sterile crossed with C.I. 187-2, Ind. 38-11, and Conn. C103, respectively, as the ear parents and Ia. L317 x Ill. Hy2 as the pollen parent. As the pericarp consists entirely of maternal tissue, the pollinator probably had no effect on the results. Each replication represented five or more ears and a 200-kernel sample was taken from each of six replications.

Table 3 — Effect of Hybrid and Maturity on Spontaneous Pericarp Injuries Occurring in Seed Corn During Drying

(Three hybrids harvested at three stages of maturity and hand-handled to avoid pericarp injury[a])

Hybrid	Stage of development when harvested	Grain moisture when harvested	Air-dry weight 100 kernels	Kernels with sound pericarps	Pericarp injury classes						Tip cap broken off
					Severe crown injury	Slight crown injury	Injury over plumule	Injury over radicle	Around edge of germ	Other pericarp injuries	
		perct.	*grams*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
187-2×WF9	Predent	56	22	96.9**	0	.3	0	.4	.4	1.9**	.1
	50-percent dented	48	28	99.2	0	.4	0	.1	.1	.2	.1
	99-percent dented	41	31	99.5	0	.3	0	.2	0	0	.1
38-11×WF9	Predent	64	20	96.6**	0	.1	0	.8	.3	2.3**	.1
	50-percent dented	54	26	98.1*	0	.3	.1	.3	.3	.9*	0
	99-percent dented	43	32	98.8	0	0	.3	.3	.8	0	0
C103×WF9	Predent	63	19	96.8**	0	0	.1	.9**	.3	1.8**	.1
	50-percent dented	51	25	99.0*	0	.2	.1	.3	.1	.4	0
	99-percent dented	41	29	99.4	0	0	.1	.1	.3	.1	.1

[a] Injuries recorded after drying presumably represent spontaneous cracks in the pericarp. It is, of course, possible that some other injuries did occur, although seed was hand-picked and carefully handled to avoid injuries.

* Significant increase or decrease (5-percent level) compared with the 99-percent dented stage. Evaluation based on angle conversions.

** Highly significant increase or decrease (1-percent level) compared with the 99-percent dented stage. Evaluation based on angle conversions.

Table 4. — Effect of Hybrid and Maturity on Mechanical Pericarp Injuries in Seed Corn Subjected to Indentical Hazard

(Three hybrids, harvested at four stages of maturity, dried to uniform moisture, and dropped 15 feet onto a smooth stone floor)

Hybrid	Stage of development when harvested	Grain moisture when harvested	Air-dry weight 100 kernels	Kernels with sound pericarps	Pericarp injury classes						Tip cap broken off
					Severe crown injury	Slight crown injury	Injury over plumule	Injury over radicle	Around edge of germ	Other pericarp injuries	
		perct.	*grams*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
187-2×WF9	Predent	56	22	33.6**	.6	18.0	.1	2.8	19.8	32.2**	.6
	50-percent dented	48	28	39.0**	1.2	16.1	0	4.5	16.8	28.0**	.8
	99-percent dented	41	31	43.8	1.0	12.2	.2	5.6	19.8	27.6**	.5
	mature	28	39	50.6	1.0	11.4	.4	4.2	12.2	14.8	.5
38-11×WF9	Predent	64	20	25.8**	1.1	21.2**	.2	4.6*	23.8	32.5**	0
	50-percent dented	54	26	32.8**	.5	12.0	.4	7.5	28.6**	28.0**	0
	99-percent dented	43	32	37.8**	.6	11.8	.2	6.8	25.8	28.6**	.1
	mature	32	39	50.8	1.8	8.5	1.0	9.8	17.8	14.8	.1
C103×WF9	Predent	63	19	22.2**	.6	24.8	.8	5.4	29.5	29.4**	0
	50-percent dented	51	25	26.1**	.4	18.4	.5	12.0*	26.1	31.4**	.2
	99-percent dented	41	29	26.8**	.6	15.5*	.8	14.5**	26.8	31.6**	.1
	mature	26	34	41.1	.1	23.8	.8	6.6	20.6	13.4	0
Summary for hybrids											
187-2×WF9	All stages	..	..	41.8	1.0	16.9	.2	4.2	17.2	25.6	.6
38-11×WF9	All stages	..	..	36.8	1.0	13.4	.4	9.2	24.0	26.0	.1
C103×WF9	All stages	..	..	29.0	.4	20.6	.7	9.6	25.8	26.4	.1
Significance of "F" value for hybrids				**	N.S.	**	*	**	**	N.S.	*

* Significant at the 5-percent level — an increase or decrease compared with the mature stage for each hybrid, or in the summary, a difference between hybrids. Evaluation based on angle conversions.

** Significant at the 1-percent level — an increase or decrease compared with the mature stage for each hybrid, or in the summary, a difference between hybrids. Evaluation based on angle conversions.

Ears were harvested at four stages of maturity and dried in racks at room temperature or by forced air at 105° F., but the method of drying apparently made no difference in the amount of spontaneous cracking. Ears were carefully shelled by hand to avoid mechanical pericarp injuries.

All hybrids showed highly significant differences in the percent of sound kernels at different stages of maturity (Table 3). On immature seed, the pericarp became wrinkled and cracks developed in the part of the kernel near the tip end; this usually occurred on the back of the kernel where it was classified as "other pericarp injuries." Differences in spontaneous cracking in this class, due to differences in maturity, also were highly significant for all hybrids. Greater differences had been observed in a previous experiment (28). Some spontaneous cracks also appeared over the radicle. Most of the cracks could not be seen without staining. Differences in the occurrence of spontaneous pericarp injury were greater at different stages of maturity than between hybrids. In the predent stage at an average grain moisture of 61 percent, spontaneous cracking was especially noticeable; it became negligible by the time 99 percent of the kernels were dented (Table 3).

Mechanical injuries. The same hybrids were used in another experiment to determine the effect of maturity and hybrid on mechanical damage. Four replications, consisting of a group of ears from each hybrid at each stage of maturity, were air dried to about 10-percent moisture and shelled by hand. The seed was then dropped 15 feet onto a smooth stone floor.

In this experiment differences between hybrids were as striking as differences due to stage of maturity (Table 4). For each hybrid, mature seed had the highest percent of sound kernels and the lowest percent of injuries around the edge of the germ and "other pericarp injuries." Differences between mature and immature seed for these two pericarp injury classes were usually highly significant (Table 4). The hybrid that had the lowest percentage of sound kernels also had the highest incidence of injured kernels within most of the injury classes (Table 4, summary for hybrids).

Effect of mechanical shelling

Type of sheller. Hybrid U.S. 13 was used in 1953 and duplicate lots were shelled with a 2-hole sheller and with a cylinder sheller. When ears were shelled with the 2-hole sheller, sound kernels averaged 62.9 percent, while with the cylinder sheller, the percentage — 50.7 — was significantly less (Table 5). More pericarp damage was caused by

Table 5. — Effect of Grain Moisture and Shelling Method on Pericarp Injuries Occurring During Shelling
(Hybrid U.S. 13, 1953 crop, shelled at various grain moistures by hand and by two types of mechanical shellers)

Grain moisture	Kernels with sound pericarps	Pericarp injury classes						Tip cap broken off	Cracked kernels
		Severe crown injury	Slight crown injury	Injury over plumule	Injury over radicle	Around edge of germ	Other pericarp injuries		
perct.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
				Hand-shelled					
12.4	97.3	0	.6	.3	.8	.1	.4	.3	0
				2-hole sheller					
29.4	39.8	13.5	9.3	7.2	20.2	4.3	14.5	23.0	4.2
24.6	45.7	8.7	7.4	6.3	13.2	6.5	12.0	10.4	6.8
21.0	54.5	5.7	6.1	5.0	12.6	3.7	9.9	6.9	5.7
17.4	61.6	3.8	3.3	5.1	11.6	4.0	9.0	6.7	4.5
14.3	72.4	2.2	2.6	3.2	8.9	3.4	5.3	4.1	3.6
11.9	82.3	2.0	2.0	3.0	5.4	1.7	2.4	2.8	1.8
9.9	75.9	2.4	3.2	2.0	9.4	3.5	4.1	1.9	.8
6.8	71.1	1.7	2.0	2.2	10.0	11.3	3.3	1.4	.8
Average	62.9	5.0	4.5	4.3	11.4	4.8	7.5	7.2	3.5
				Cylinder sheller					
29.4	33.0	14.5	5.3	5.0	26.2	14.0	17.3	19.2	5.2
24.6	39.1	11.1	10.9	6.6	12.0	15.2	18.9	11.4	5.9
21.0	49.8	8.7	10.3	5.8	9.4	10.9	13.2	6.0	5.6
17.4	55.5	6.6	10.0	8.1	7.6	10.8	10.6	5.1	4.5
14.3	57.8	5.1	7.4	7.4	6.4	12.0	9.9	4.0	4.7
11.9	63.0	2.8	5.2	5.0	9.0	10.9	9.1	2.3	2.0
9.9	55.4	2.0	4.7	2.4	14.5	16.1	12.8	2.4	1.4
6.8	52.5	3.4	6.3	2.5	15.9	15.0	15.7	2.0	2.0
Average	50.7	6.8	7.5	5.3	12.6	11.9	13.4	6.6	3.9
L.S.D. (5-percent level) for moisture	3.5	2.6	1.9	3.3	6.5	2.0	2.5	3.3	3.0
L.S.D. (5-percent level) for sheller	1.3	.9	.2	N.S.[a]	N.S.	.7	.9	N.S.	N.S.

[a] Not significant.

Table 6. — Effect of Grain Moisture on Pericarp Injuries Occurring During Shelling
(Hybrid Ill. 972-A1, 1948 crop, shelled at various grain moistures with a 2-hole sheller)

Grain moisture	Kernels with sound pericarps	Pericarp injury classes						Tip cap broken off	Cracked kernels
		Severe crown injury	Slight crown injury	Injury over plumule	Injury over radicle	Around edge of germ	Other pericarp injuries		
perct.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
34.4	34.8	11.7	8.6	7.7	36.6	12.6	17.6	9.8	25.5
32.2	38.3	10.6	6.8	4.5	35.7	6.0	15.0	11.7	22.0
29.6	41.5	6.9	7.5	5.3	25.0	6.6	17.8	18.7	16.8
27.8	41.0	4.9	4.4	4.7	18.5	5.8	15.8	28.3	13.0
25.0	52.8	3.3	3.3	3.9	25.5	4.8	14.1	19.3	8.0
23.6	56.0	4.8	4.8	6.8	18.2	3.8	13.2	12.1	8.4
19.7	70.5	3.1	3.2	1.8	10.0	3.6	7.2	8.7	4.0
18.9	73.5	3.7	3.2	1.7	9.4	2.4	7.4	6.3	4.5
16.7	78.8	2.1	2.7	3.6	8.3	.6	4.2	4.9	2.5
15.8	82.0	2.0	3.0	3.6	8.8	1.8	2.4	1.7	1.8
15.1	82.1	2.6	2.4	.8	4.6	1.2	3.0	4.5	3.0
13.3	79.2	2.6	2.3	2.0	8.8	.6	.6	7.7	2.5
11.7	83.8	3.3	3.0	.8	6.0	1.2	1.8	2.3	2.0
10.8	84.3	2.6	2.7	1.2	2.4	2.2	1.8	3.6	2.5
9.0	85.8	1.8	3.0	1.2	5.6	.6	1.2	1.3	2.8
7.1	81.0	3.1	4.7	1.2	4.3	3.4	2.4	2.9	3.0
6.2	85.1	3.0	5.3	.8	3.2	1.6	.6	2.2	1.0
5.1	83.1	3.3	5.3	1.2	3.7	2.2	2.4	2.3	1.2
4.4	81.5	3.3	6.2	2.1	3.4	4.0	1.2	2.3	2.0
Correlation coefficients with moisture.....	−.93**	.76**	.43	.83**	.93**	.73**	.94**	.75**	.88**

** Significant at the 1-percent level.

the cylinder sheller than by the 2-hole machine, especially crown injuries, injuries around the margin of the germ, and "other pericarp injuries." These differences also were significant (Table 5). The cylinder sheller was operated in the manner and at the speed determined at the factory. Changes could probably have been made to markedly reduce the pericarp damage.

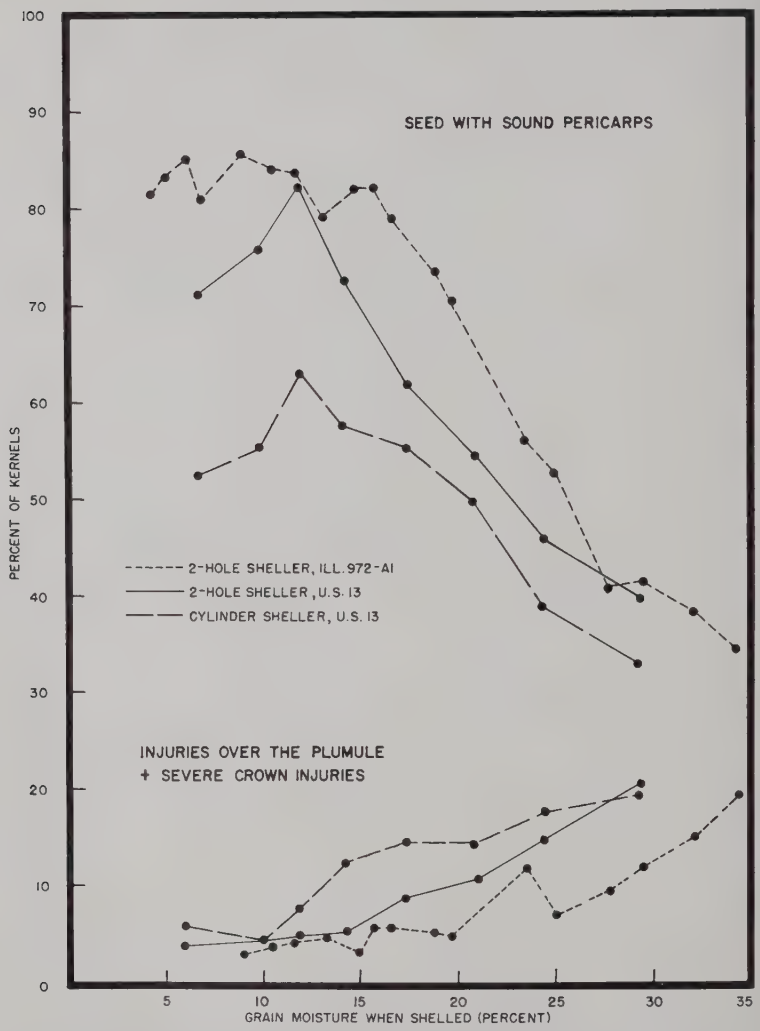
Grain moisture at shelling. Hybrid Ill. 972-A1 was shelled with a power 2-hole sheller in 1948. Ears shelled at high moisture were harvested at the desired moisture condition. Those shelled at low moisture were dried at about 105° F. with forced air to the desired moisture. After shelling, seed with over 12-percent moisture was dried to 12 percent. All samples were passed through a small motor-driven grader and a Boerner divider was used to obtain several 200-kernel samples from the medium and large flats.

The highest percentage of sound kernels of Ill. 972-A1 occurred when the seed was shelled at 5 to 16.7 percent moisture. Differences were not significant through that range. But from 16.7 percent, sound kernels began to decrease sharply with increases in moisture (Table 6, Fig. 5). Correlation coefficients show a highly significant positive correlation between grain moisture and number of pericarp injuries for all injury classes except slight crown injury (Table 6).

Similar results were obtained with U.S. 13. In this experiment, two types of shellers were used. The highest percentage of sound kernels occurred at about 12-percent moisture with both kinds of shellers (Table 5, Fig. 5). There was a significant decrease in the number of sound kernels at lower or higher moistures. With few exceptions, the various kinds of injury were most numerous at the highest moisture and least near 12 percent. Severe crown injury, injury over the plumule, other pericarp injuries, and tip cap broken off had the closest correlations with moisture at shelling time.

Tatum and Zuber (44) reported data for shelling at only two grain moistures. They reported about twice as much kernel injury at 7.6 percent as at 12.0 percent. Considering data from the tests reported here, it appears that the least total pericarp damage occurs when corn is shelled at about 12 percent moisture and the least of the two most damaging types of injury occurs at about 10 percent moisture (Fig. 5).

Huelsen and Brown (21) found a much higher moisture to be favorable for shelling sweet corn; the best grain quality was assured when the corn was shelled at 20 to 25 percent.



Effect of grain moisture at shelling. The percent of sound kernels decreased while the percent of kernels with severe crown injury and injury over or near the plumule — the most severe in their effects on seedling susceptibility to blight — increased at high grain moistures. Two hybrids and two different types of sheller were used. (Fig. 5)

EFFECT OF PERICARP INJURIES ON SEEDLING GROWTH, YIELD, AND RESISTANCE TO BLIGHT IN NATURALLY INFESTED SOIL

The effects of various types of pericarp injury on seedling growth were compared by the "cold test" method and in field tests on the Agronomy South Farm. None of the seed used in these experiments had been treated with a fungicide, unless specifically mentioned. A literature review on cold testing has been published by Wernham (45).

Seed with unsorted pericarp injuries

Cold tests. Seed of hybrid U.S. 13 that had been shelled at various grain moistures was tested for germination. All seed, whether hand-shelled or machine-shelled, germinated well on Kimpack in a warm germinator, but the results were quite different when the seed was planted in naturally infested soil and kept at 50° F. for 10 days. Hand-shelled seed, with 97.3 percent sound kernels, produced a stand of 90 percent, but the best stand from machine-shelled seed was 73.3 percent (Table 7). Best stands and green weights from machine-shelled seed were obtained when the seed was shelled at 6.8 to 12 percent moisture; both stand and green weight decreased rapidly as the moisture at shelling increased.

Field tests. Such differences as are mentioned above are, of course, especially prone to show under adverse growing conditions as occurred in the cold tests. Under average field conditions, there would not usually be such marked differences between the performances of sound and injured seed. However, in a three-year field test on the Agronomy South Farm, when seed was not treated with a fungicide, commercial seed produced stands of 84.1 percent, while the stand from hand-handled seed was 93.6 percent (Table 8). Here again, the obvious difference between the two seed lots was in pericarp condition. Commercial seed had an average of only 18.6 percent sound kernels, while hand-picked seed averaged 94 percent sound (Table 8).

Considerable differences in yield also occurred in the field tests. Acre yields for commercial seed averaged 87.1 bushels, while hand-shelled seed averaged 96.9 bushels. Such differences as were noted in stand would not result in such differences in yield if stand were the only factor affecting yield. But while there is a greater loss in stand from pericarp-injured seed due to seedling blight from soil-borne infection, there is also a reduction in the average vigor of plants when the seed has been injured (28).

Importance of type of injury

Cold tests. Commercial samples of seed were examined for pericarp injury and samples from each injury class (Table 1) were saved for determining their relative susceptibilities to damage by seedling blight. Only kernels with one type of injury were used in these tests; those with multiple injuries were discarded. Except for crown injury,

Table 7. — Effect of Shelling Method and Grain Moisture at Shelling on Stand and Green Weight in Cold Tests

(Hybrid U.S. 13, 1953 crop, shelled at various grain moistures by hand and and by two types of mechanical sheller, and planted in naturally infested soil, kept at 50° F. for 10 days and at 70°-75° F. for 11 days. Part of the seed was treated with Arasan SF-X, ¾ ounce per bushel.)

Grain moisture at shelling	Kernels with sound pericarps[a]	Stand		Green weight[b]	
		Untreated	Treated	Untreated	Treated
perct.	*perct.*	*perct.*		*grams*	
		Hand-shelled			
12.4	97.3	90.0	97.5	55.9	60.4
		2-hole sheller			
29.4	39.8	22.8	43.3	10.3	19.9
24.6	45.7	27.8	49.4	14.2	23.6
21.0	54.5	32.8	54.4	17.0	25.8
17.4	61.6	41.7	61.1	22.1	31.2
14.3	72.4	63.3	78.9	36.6	45.4
11.9	82.3	73.3	86.7	43.7	49.4
9.9	75.9	72.2	86.1	43.7	49.0
6.8	71.1	71.7	88.9	42.4	51.7
Average	62.9	50.7	68.6	28.8	37.0
		Cylinder sheller			
29.4	33.0	16.1	36.7	7.7	15.6
24.6	39.1	24.4	37.8	11.7	17.1
21.0	49.8	25.6	50.0	13.7	23.1
17.4	55.5	30.6	52.8	15.9	26.0
14.3	57.8	47.7	61.1	27.0	33.0
11.9	63.0	60.0	75.0	35.1	44.9
9.9	55.4	65.0	78.3	38.1	44.7
6.8	52.5	53.9	79.4	36.9	46.3
Average	50.7	40.4	58.9	23.3	31.3
L.S.D. (5-percent level) for moisture	3.5	9.3	7.2	5.8	5.9
L.S.D. (5-percent level) for sheller	1.3	2.6	3.1	1.7	1.9

[a] The distribution of the various types of pericarp injury is given in Table 5.
[b] Green weight of plants from 100 seeds planted.

which was divided into "severe" and "slight," each injury class represented, as nearly as possible, a random sample regardless of the extent of injury. One replication of one test is shown in Fig. 6. In the cold tests, the most severe seedling blight occurred when the seed had severe crown injuries. Slight crown injury was important in this respect, but not to as great an extent. The green weight per plant was reduced more with both types of crown injury than with any other type of pericarp damage (Table 9). Stands were greatly reduced when the injury was over the plumule, but the plants that survived had fairly good vigor. This effect was consistent for the various years. The results

Table 8. — Effect of Pericarp Injuries on Stand and Yield in Field Tests With and Without Seed Treatment

(Three-year average of Hybrids U.S. 13 and Ill. 972-A1, seed treated with several protective fungicides at various rates[a])

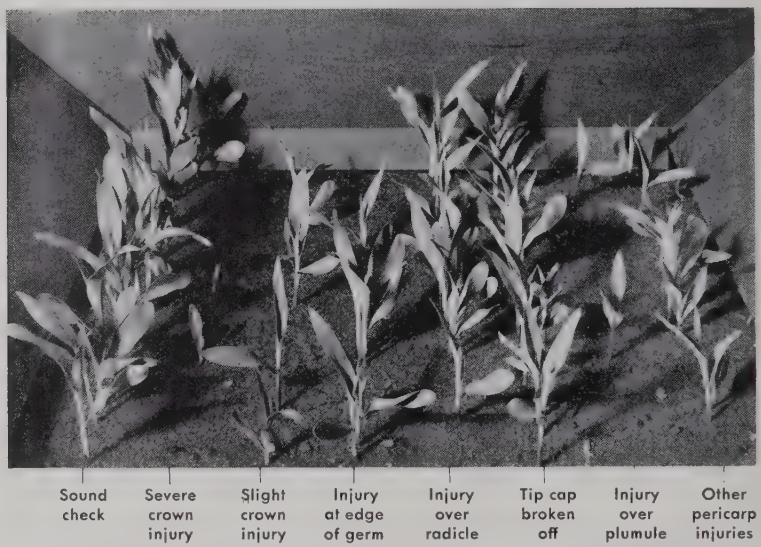
Seed treatment		Commercial seed[b]		Hand-injured seed[b]		Hand-handled seed[b]	
Fungicide	Rate (oz. per bu.)	Stand and yield	Increase over check	Stand and yield	Increase over check	Stand and yield	Increase over check
				Stand (percent)			
None (check)	..	84.1	.....	80.9	.....	93.6	...
Arasan SF[a]	½	91.6	7.5**	92.2	11.3**	94.9	1.3
	1	92.0	7.9**	93.8	12.9**	95.1	1.5
Spergon DDT-SL[a]	½	89.0	4.9*	87.7	6.8**	93.9	0.3
	1	89.6	5.5**	89.7	8.8**	94.3	0.7
Phygon[a]	½	89.8	5.7**	92.0	11.1**	94.0	0.4
Average for treatments		90.4	6.3**	91.1	10.2**	94.4	0.8
				Yield (bushels)			
None (check)	..	87.1	.....	84.7	.....	96.9	...
Arasan SF	½	94.3	7.2**	94.8	10.1**	97.7	0.8
	1	95.9	8.8**	96.3	11.6**	97.6	0.7
Spergon DDT-SL	½	93.1	6.0**	92.3	7.6**	96.6	−0.3
	1	93.7	6.6**	94.1	9.4**	98.2	1.3
Phygon	½	94.0	6.9**	93.2	8.5**	96.2	−0.7
Average for treatments		94.2	7.1**	94.1	9.4**	97.3	0.4

[a] Arasan SF, active ingredient 75 percent thiram; Spergon DDT-SL, active ingredient 92 percent chloranil plus 3 percent DDT; and Phygon XL-DDT, active ingredient 50 percent 2,3-dichloro-1,4-napthoquinone plus 3 percent DDT.

[b] Commercially processed seed contained kernels with various types of pericarp injuries, 18.6 percent sound kernels. Hand-injured seed had been handpicked; all were cut with a knife to injure the crown pericarp. Hand-handled seed had been carefully picked and handled to avoid any injuries, and had 94 percent sound kernels.

* Significant at the 5-percent level.

** Significant at the 1-percent level.



Differences in stand and vigor caused by seedling blight in a cold test with sound and pericarp-injured seed. All kernels were sorted from commercial seed samples. (Fig. 6)

of six crop years of cold tests are shown in Table 9, with the injury classes arranged in the order of their average importance. Both stand and green weight were significantly reduced for seed with all types of injury, including broken tip caps, as compared with sound seed.

One surprising result in this series of tests was the superior performance of hand-handled seed over healthy-appearing seed with sound pericarps sorted from commercial samples. The average stand for commercial sound seed was 88.5 percent; the hand-handled seed of U.S. 13 in 1953 produced a stand of 94.6 percent (Table 9). It is unlikely that the commercial seed sorted as "sound" had undetected injuries, as the samples were stained before sorting. This may lend support to Livingston's conclusion (33) that artificial drying in itself has a damaging effect on the vitality of seedlings and their resistance to blight.

Field tests. Yield comparisons were made from data obtained in the Agricultural Experiment Station's hybrid corn test in 1954 (38). This test was selected for study because differences in stands between

Table 9. — Effect of Type of Pericarp Injury on Stand and Green Weight in Cold Tests

(Seed of commercial hybrids, 6 crop years, and of U.S. 13, 1952 crop planted in naturally infested soil at 50° F. for 10 days, then placed in a greenhouse at 70°-75° F.)

Pericarp condition	Average, many hybrids, 1944-1953	Hybrid U.S. 13, 1952		
	Stand	Stand	Green weight from 100 seeds planted	Green weight per plant
	perct.	*perct.*	*grams*	*grams*
Mechanically processed seed				
Severe crown injury	17.4	2.7	.5	.185
Injury over plumule	24.2	14.7	9.4	.639
Slight crown injury	36.2	26.0	8.4	.323
Injury at margin of germ area	36.0	27.3	13.7	.502
Other pericarp injuries	44.8	34.0	17.9	.526
Injury over radicle	44.9	32.0	19.9	.622
Tip cap broken off	61.1	48.7	29.2	.600
Sound	88.5	74.7	48.1	.644
Hand-handled seed				
Sound	....	94.6	71.4	.755
L.S.D. (5-percent level)	9.1	10.2	6.5	.079

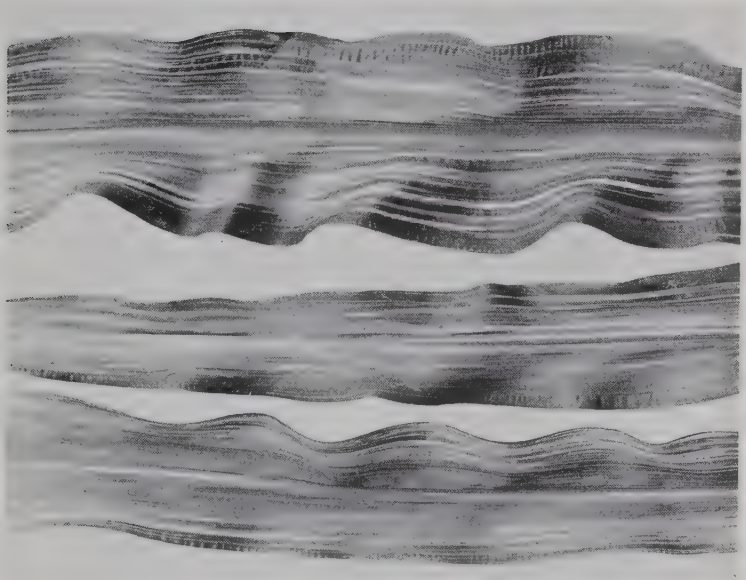
hybrids appeared to be the result of seedling blight, although all seed had been treated before planting with a protective fungicide Reductions in stand and yield were both highly correlated with severe crown injury (Table 10). When crown injury was slight the correlation was still significant at the 5-percent level. Injury near plumule showed a higher negative correlation with stand than with yield. This field test supports the conclusions derived from the cold tests: that while pericarp injury at the crown and over the plumule both contribute to severe losses in stand from seedling blight, the plants that survive have the poorest vigor when the seed pericarp has been injured at the crown.

Data from the 1955 commercial hybrid tests showed highly significant correlations between stand and yield in two of the five tests in Illinois (32). The results of the Carbondale test, which were studied for relationships between stand, yield, and pericarp condition, showed correlations similar to those noted in 1954. However, negative correlations with stand and yield were significant only for severe crown injury and "other pericarp injuries."

Table 10. — Correlations Between Type of Pericarp Injury and Stand and Yield in Field Test[a]

Yield classes	Average acre yield	Average field stand	Pericarp injury classes[b]						Tip cap broken off	Kernels with sound pericarps
			Severe crown injury	Slight crown injury	Injury over plumule	Injury over radicle	Around margin of germ	Other pericarp injuries		
	bu.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*
12 highest yielding entries	116.5	90.9	5.7	15.3	17.5	53.8	46.5	16.2	3.0	8.5
12 medium yielding entries	108.1	85.1	8.0	19.5	18.3	50.8	40.3	18.7	7.0	11.7
12 lowest yielding entries	95.3	79.3	13.0	28.9	27.2	62.0	37.6	33.8	7.0	5.4
Correlation coefficient among above 36 entries										
With field stand	.73**	...	−.44**	−.35*	−.45**	−.16	−.27	−.49**	−.36*	+.03
With acre yield	....	.73**	−.56**	−.41*	−.33*	−.15	−.22	−.46**	−.27	+.08

[a] Based on results from the experimental field at DeKalb, reported in 1954 Illinois Corn Tests, Ill. Agr. Exp. Sta. Bul. 585:16-17.
[b] Samples of seed lots used in the field tests were examined for pericarp condition.
* Significant at the 5-percent level.
** Significant at the 1-percent level.



Striped leaves such as these occurred on some plants in field plots in several years, but only where pericarp-injured seed had been planted. (Fig. 7)

Plants with striped leaves (Fig. 7) were observed in field plots in 1937 and particularly in 1939. They occurred in all replicates planted with seed that had the pericarp partially removed from the crown, but did not appear in plots planted with sound seed. In the 1939 field experiment, average percentages of striped plants were as follows: Station strain of Reid Yellow Dent, 10.8; hybrid Ill. 960. 3.2; and hybrid U.S. 13, 5.7 percent. In the young plant stage, the striped plants did not average more than one-half the height of nonstriped ones. After the plants had attained all their leaves, the upper leaves were observed to be free from striping, especially those above the ear shoot. The plants could not be removed for attempts at isolating fungi, because the test had been planted for yield determinations. However, C. M. Woodworth of the Illinois Station selfed a number of the most vigorous striped plants and obtained some seed, which was planted the next year. No striped plants appeared. Thus it seems clear that this striping was not of a heritable nature and must have been a disease symptom.

Some virescent plants have been observed in field tests. When cold

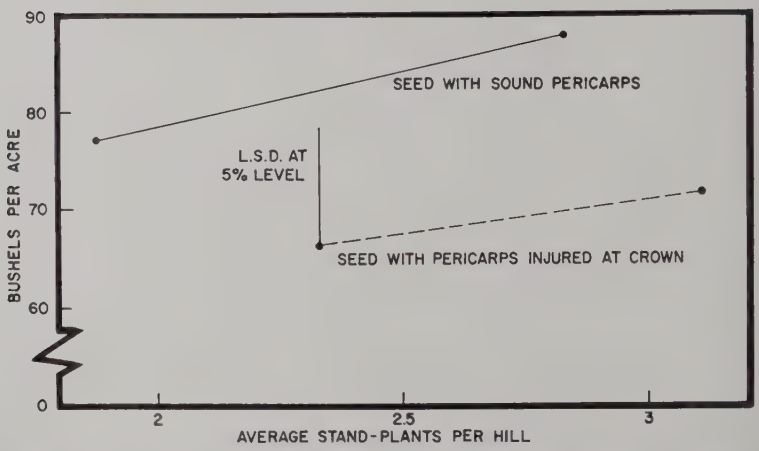
tests were conducted with *Aspergillus flavus* and *A. tamarii* inoculations, virescence occurred among plants from pericarp-injured seed. This effect is discussed further on pages 46 and 47.

Yield comparisons for similar stands

Field plots were planted with untreated sound and injured seed to compare yield when stands were the same. Seed with sound pericarps from hand-handled seed was planted at the rates of 2 and 3 kernels per hill. Seed from the same ears with part of the crown pericarp removed was planted at the rates of 3 and 4 kernels per hill.

Actual stands obtained, as a seven-year average, for seed with sound pericarps planted at 2 kernels per hill were 1.88 plants per hill, at 3 kernels per hill, 2.83; for seed injured at the crown, stands were 2.33 plants per hill when planted at 3 kernels per hill, and 3.11 plants at 4 kernels per hill.

Comparing acre yields with the actual stand obtained (Fig. 8), it may be seen that there is a range within which theoretically identical stands can be compared. There was an average calculated difference in yield of 16.5 bushels between plants from sound seed and plants from seed with the crown pericarp injured, when stands were identical. This difference was significant at the 5-percent level.



Differences in yield from untreated seed with sound and injured pericarps. Seed was planted at several rates so that yields from the same field stands could be compared. (Fig. 8)

Effect of temperature on preemergence growth of sound and injured seed. Rows 1 and 3, pericarp partially removed from the crown; 2 and 4, sound pericarp. Seed shown in rows 3 and 4 were treated with the protective fungicide, Arasan, at the rate of 1 ounce per bushel. (Fig. 9)

Table 11. — Effect of Temperature, Pericarp Condition, and Seed Treatment on Preemergence Growth and Pythium Infection of Seedlings

(Hybrid U.S. 13, part sound and part with the pericarp partially removed from the crown, planted in moist field soil and kept constantly at 50°, 60°, or 70° F. Part of seed of both pericarp conditions was treated with Arasan.)

Temperature (° F.)	Seed treatment (oz. per bu.)	Days after planting	Figure 9, row no.	Pericarp breakage due to growth of germ	Radicle visible	Plumule visible	Pythium-infected germ area
				perct.	*perct.*	*perct.*	*perct.*
			Seed with crown pericarp injured				
50	None	2		0	0	0	0
		3		0	0	0	10
		4		0	0	0	57
		6		21	0	0	73
		7	A	27	9	0	93
		9		52	15	0	100
		12	B	64	24	6	100
		17	C	58	21	3	100
	1	7	A	73	49	0	0
		12	B	100	100	27	0
		17	C	100	100	91	20
60	None	2		12	6	0	3
		3		79	49	0	23
		4		97	94	6	67
		5		100	100	70	93
		6		100	100	94	100
		7	D	100	100	100	100
	1	5		100	100	61	0
		6		100	100	100	3
		7	D	100	100	100	3
70	None	1		3	3	0	0
		2		100	100	0	30
		3		100	100	100	97
		4	E	100	100	100	100
		5		100	100	100	100
	1	3		100	100	100	0
		4	E	100	100	100	0
		5		100	100	100	10
			Seed with sound pericarps				
50	None	7	A	70	49	0	0
		9		85	76	0	10
		12	B	100	88	9	43
		17	C	100	94	46	57
	1	7	A	64	52	0	0
		12	B	100	100	18	0
		17	C	100	100	79	7

(Table is concluded on next page)

Table 11. — Concluded

Temperature (° F.)	Seed treatment (oz. per bu.)	Days after planting	Figure 9, row no.	Pericarp breakage due to growth of germ	Radicle visible	Plumule visible	Pythium-infected germ area
				perct.	*perct.*	*perct.*	*perct.*
60	None	5		100	100	64	0
		6		100	100	100	0
		7	D	100	100	100	7
	1	5		100	100	58	0
		6		100	100	100	0
		7	D	100	100	100	0
70	None	3		100	100	100	0
		4	E	100	100	100	3
		5		100	100	100	3
	1	3		100	100	100	0
		4	E	100	100	100	0
		5		100	100	100	0

Effect of temperature

Preemergence growth at three temperatures. Good quality seed of U.S. 13, part of which had the pericarp partially removed from the crown, was tested for preemergence growth in natural soil at three temperatures. Only the data for the untreated samples will be considered here.

At 50° F. when the pericarp had been injured at the crown, rupturing of the pericarp over the germ due to swelling or growth began on the fifth day and had reached 64 percent by the twelfth day, but none of the plumules had emerged enough to be measurable (Table 11, Fig. 9). After 12 days at 50° F., no further growth took place, as all embryos or seedlings had died from Pythium blight. Not even sound seed emerged from the soil when kept constantly at 50° F. unless it had been treated with a protective fungicide. This is approximately the temperature at which the most damage from certain Pythium species occurs. At lower temperatures — for example, 45° or 39° F. — others (9, 18) have found seedling blight less severe.

At 60° F., pericarp breakage due to embryo growth began in crown-injured seed in 2 days. Radicles were measurable in 4 days and plumules in 5 days. Plumules did not start to emerge from the soil until the tenth day. This temperature and pericarp condition was favorable to Pythium invasion, which reached 100 percent on the sixth day in

crown-injured seed (Table 11). As a result, the injured seed showed retarded growth of plumules and radicles, compared with that of sound seed.

At 70° F., a few pericarps had split open due to growth in one day after planting. Radicles were measurable on the second day, plumules on the third. At this temperature, although Pythium invasion was high in injured seed within a few days, there was comparatively little difference in growth rate between injured and sound seed (Table 11, Fig. 9). Seedlings emerged from the soil in 5 days.

Delayed exposure to cold. An experiment was conducted with four hybrids to determine the effect of delaying exposure to cold after planting. Part of the seed had the pericarp partially removed from the crown. The trays were kept at 50° F. for 10 days in all cases, but as more time elapsed between planting and exposure to cold, better stands were obtained. Furthermore, the longer after planting the cold period was delayed, the less difference there was in stands from sound and from injured seed, due to the improved results from injured seed (Table 12).

Thus it appears that resistance to seedling blight resulting from soil

Table 12. — Effect on Stand of Delaying Exposure of Sound and Pericarp-Injured Seed to Cold After Planting

(Four hybrids planted in naturally infested soil and kept at 70° F. up to 3 days before a 10-day period at 50° F.)

Pericarp condition	Days at 70° F. before cold period	Days at 70° F. after cold period	Stand (angles)				
			Hybrid				Mean
			A	B	C	D	
Crown pericarp partially removed	0	11	63	40	33	27	41
	1[a]	10	61	60	54	46	55
	2[b]	9	77	80	72	70	75
	3[c]	8	87	80	82	65	78
Sound	0	11	82	77	78	47	71
	1	10	87	74	87	70	80
	2	9	83	87	87	85	86
	3	8	90	87	90	87	89
L.S.D. (5-percent level), both pericarp conditions			10	10	10	10	6

[a] No radicles or plumules had broken through the pericarp the first day.
[b] Radicles up to 0.4 inches long. Plumules had not broken through the pericarp.
[c] Radicles 0.4 to 2.5 inches long. Plumules 0.2 to 0.5 inches long. No emergence above the soil.

Table 13. — Effect of Soil Moisture and Pericarp Condition on Stand and Green Weight at Two Temperatures

(Hybrid U.S. 13, sound pericarps and two types of injury, planted in naturally infested soil adjusted to three levels of moisture[a] and kept constantly at 60° or 70° F.)

Pericarp condition	Soil moisture	Days after planting[b]		Stand		Green weight[c]	
		60° F.	70° F.	60° F.	70° F.	60° F.	70° F.
				angle		*grams*	
Pericarp injury near plumule	Low	25	16	73	88	41	48
	Medium	22	15	53	82	25	44
	High	20	14	34	68	19	39
Pericarp injured at crown	Low	25	16	73	90	28	48
	Medium	22	15	58	87	27	49
	High	20	14	45	73	22	41
Sound	Low	25	16	86	88	64	60
	Medium	22	15	87	90	66	63
	High	20	14	85	87	67	69
L.S.D. (5-percent level)		..	..	12	11	10	9

[a] Soil was adjusted to 45 (low), 65 (medium), and 80 (high) percent of the moisture-holding capacity, which was found to be about 40 percent based on dry weight, in the manner in which it was used in this experiment.

[b] Data were recorded after sound seed reached the three-leaf stage. Plants from injured seed were harvested at the same time, regardless of the number of leaves.

[c] Green weight of plants from 100 seeds planted.

infestation increases as germination becomes active, and the more days germination can proceed in warm soil, the greater the resistance regardless of pericarp condition.

Effect of soil moisture

It has been shown that high soil moisture increases damage from Pythium seedling blight (8), but previous reports have not mentioned the effect of the pericarp condition. In this test it was desired to know how moisture affects growth in infested soil when the pericarp conditions of the seed differ. Injuries were made by shaving off part of the crown pericarp and by making slight cuts to one side of the plumule (Fig. 10A, page 39). Four replications of 25 seeds of one kind were planted in naturally infested soil in 2-gallon cans and kept at 60° and 70° F. in apparatus known as the Wisconsin Soil Temperature Tanks (25). The soil was adjusted to three levels of moisture: 45, 65, and 80 percent of the moisture-holding capacity. As used in this experiment, the soil was found to have a water-holding capacity of about 40 percent based on dry weight.

At all three moisture levels, sound seed produced significantly better green weights than seed with either type of pericarp injury (Table 13).

Differences in stand due to differences in pericarp condition were significant only at 60° F. At both temperatures the rate of growth for sound seed was faster as soil moisture increased, due to protection by the pericarp. But the opposite was true of plants grown from injured seed (Table 13); where there was little protection from the pericarp, disease damage increased greatly with increases in moisture. This was significant at 70° F., but most outstanding at 60° F. There was little difference in results between the two types of pericarp injury at the different soil moistures.

EFFECT OF PERICARP INJURIES ON SEEDLING BLIGHT CAUSED BY SPECIFIC FUNGI

Fungus isolations

Fungi were isolated from seed of hybrid U.S. 13 that had been planted in moist, naturally infested soil. The ears had been hand-picked, tested, and selected for freedom from internal infection, then surface-disinfested with a solution of sodium hypochlorite. Part of the seed was injured by removing part of the crown pericarp. After seed was removed from the soil, it was cleaned with a soft toothbrush under running tap water. Radicles and plumules longer than ½ inch were clipped, and seed was then washed and agitated under running water for one hour. A small piece of tissue midway across the scutellum, including a little of the central node of the embryo and a bit of the endosperm, was removed asceptically and plated on plain water agar. After two days a hyphal tip was isolated from each colony and manipulated to free the isolates of bacteria. The original piece of tissue was left in the Petri dish for several more days.

Pythium species were the first invaders of both sound and crown-injured seed. Pythium was found in a small percentage of the injured seeds two days after planting at 60° F., and in three days at 50° F. Isolations were not obtained from seed with sound pericarps until the fourth day at 70° F., the seventh day at 60° F., and the eighth day at 50° F. (Table 11). More than half of the Pythium isolates were identified as *P. debaryanum* Hesse. Most of the remainder could be classed as closely related or similar forms, one of which was identified several times as *P. ultimum* Trow. *P. ultimum* appeared to be the most common species causing seedling blight in some Wisconsin soils (20). However, studies in Iowa (10) showed *P. debaryanum* to be the chief cause of seed decay and stunted growth of seedlings. Sprague (42) also found it to be the most common of the sphaerospo-

rangial species attacking Graminae in North Dakota and surrounding regions. Many of the isolates could not be more closely identified because sporangia, oogonia, and antheridia — all necessary for identification — were not all obtained in culture.

Among these early isolations some pieces plated had bacteria as well as Pythium, and some produced only bacteria. It seemed doubtful, however, that these bacteria were of much pathological significance.

Other fungi appeared rather frequently in tissue from crown-injured seed plated six or more days after planting at 50° F., or earlier at warmer temperatures. Among these were Penicillium species, including *P. oxalicum; Fusarium moniliforme;* Trichoderma species; *Cephalosporium acremonium;* Helminthosporium species; Sporodinia species; Mucor species; and unidentified fungi. Some of these may have been carried in or on the seed, although it had been tested and selected for freedom from internal infection and disinfested with sodium hypochlorite before planting.

Seed inoculation experiments

Comparisons between damage from blight in plants grown from sound seed and those from seed with pericarp injuries were made by inoculating seed of various pericarp conditions with each of the following fungi: *Pythium debaryanum* Hesse, *Penicillium oxalicum* Currie and Thom, *Aspergillus flavus* Link, *A. tamarii* Kita, *A. niger* Van Tieghem, *Diplodia zeae* (Schw.) Lev., *Gibberella zeae* (Schw.) Petch, *Fusarium moniliforme* Sheldon [*G. fujikuroi* (Saw.) Wr.], *Trichoderma viride* (Pers. ex Fries) Bisby, and miscellaneous Penicillium and Aspergillus species.

Pythium debaryanum. The extent of seedling blight caused by sphaerosporangial seed-rotting Pythium species is greatly influenced by the condition of the pericarp. Whether this is also true for the lobulate-sporangial forms, *P. arrhenomanes* and *P. graminicola,* has not been determined and they rarely occurred in these isolations. That this relationship is true of some *Pythium* species, then unidentified, was previously reported by the writer (23).

A highly virulent strain of *Pythium debaryanum* was selected for inoculation. A transplant was sent to T. C. Vanterpool,[1] a specialist in Pythium taxonomy, who verified the writer's identification. Cultures were grown on potato dextrose agar in 100 mm. Petri dishes. Four cultures 4 to 5 days old were macerated with 200 ml. water in a Waring

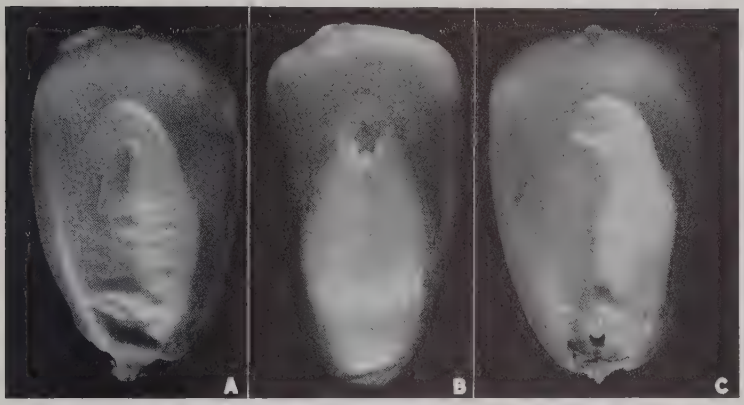
[1] Professor of Plant Pathology, University of Saskatchewan.

Table 14. — Effect of Seed Inoculations with *Pythium debaryanum*[a] and *Penicillium oxalicum*[b] on Stand, Growth, and Green Weight of Plants From Pericarp-Injured Seed

(Hybrid U.S. 13 planted in disinfested sand, kept at low temperature for 7 days and then placed in a greenhouse at 70°-75° F.)

Pericarp condition	Stand				Growth index[c]		Green weight per 100 seeds planted		Green weight per plant	
	Pythium	Penicillium	Pythium	Penicillium	Pythium	Penicillium	Pythium	Penicillium	Pythium	Penicillium
	perct.		*angle*				*grams*		*grams*	
Crown pericarp partially removed from crown	27	46	31	43	19	14	5	4	.19	.09
Slightly cut along plumule	61	85	51	67	56	72	22	30	.36	.35
Injured at margin of germ area	67	99	55	84	56	83	23	39	.34	.39
Crown punctured	81	76	64	61	63	28	21	8	.26	.11
Horny endosperm exposed	83	92	66	74	62	58	26	23	.31	.25
Radicle exposed	86	98	68	82	67	78	30	37	.35	.38
Tip cap broken off	89	100	71	90	81	97	41	57	.46	.57
Sound	95	100	77	90	90	98	50	60	.53	.60
L.S.D. (5-percent level)	..	..	8	8	9	9	5	5	.05	.05

[a] *Pythium debaryanum* inoculations were made with a macerated agar culture suspension. Seed was kept at 50° F. the first seven days after planting.
[b] *Penicillium oxalicum* inoculations were made with a spore suspension. Seed was kept at 65° F. the first seven days after planting.
[c] Based on a value of 100 for a perfect stand of plants with 3 leaves (see page 11).



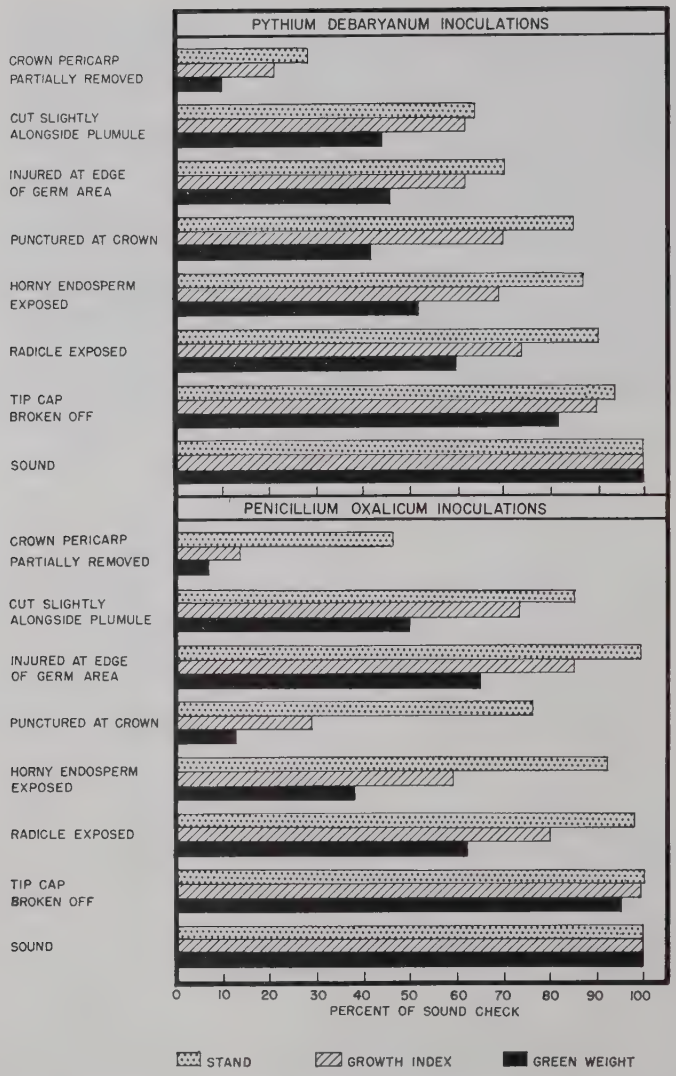
Pericarp injuries made by hand. A. A slight cut alongside the plumule, as used in experiments reported in Tables 13, 14, 15, and 20. B. Plumule exposed, Table 17. C. Radicle exposed, Tables 14, 15, and 17. (Fig. 10)

Blendor for 15 to 20 seconds before covering the seed. The seed was soaked for several minutes in the suspension with occasional stirring, drained, then planted in disinfested Torpedo sand and natural soil.

The above-ground symptoms from Pythium inoculations were primarily poor stands and weak plants, often pale in color, following subjection to cold temperature, and weak plants lower in green weight when grown at 70°-75° F. There were no specific foliage symptoms. Similar observations were reported by Hoppe (17).

Relative susceptibility ratings for seed with various kinds of pericarp injury and different genetic constitution were very nearly the same, regardless of whether they were inoculated and planted in disinfested sand or noninoculated and planted in naturally infested soil. Inoculation had no additional effect on disease development in natural soil.

Seed of U.S. 13 with various types of pericarp injury made by hand was inoculated with a pure culture of *Pythium debaryanum,* planted in disinfested sand, and kept at 50° F. for seven days before placing in a warm greenhouse. (Fig. 10 shows a light cut along the plumule and an exposed radicle.) Results in this test (Table 14) were similar to those obtained with seed injured during commercial processing planted in natural field soil (Table 9). In both sets of experiments, green weights were reduced more by crown injuries, severe or slight, than by any other type of pericarp damage (Tables 9 and 14). Injuries

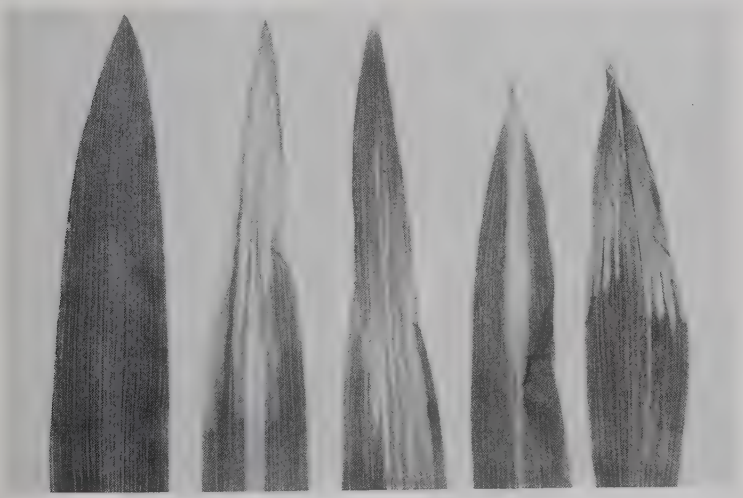


Three methods of measuring seedling development. Seed with various types of pericarp injury made by hand was inoculated at planting with *Pythium debaryanum* or *Penicillium oxalicum*. Stand, green weight, and growth index are adjusted here to give a value of 100 for the sound check. (For actual stand percentages obtained in inoculation tests, see Table 14.) (Fig. 11)

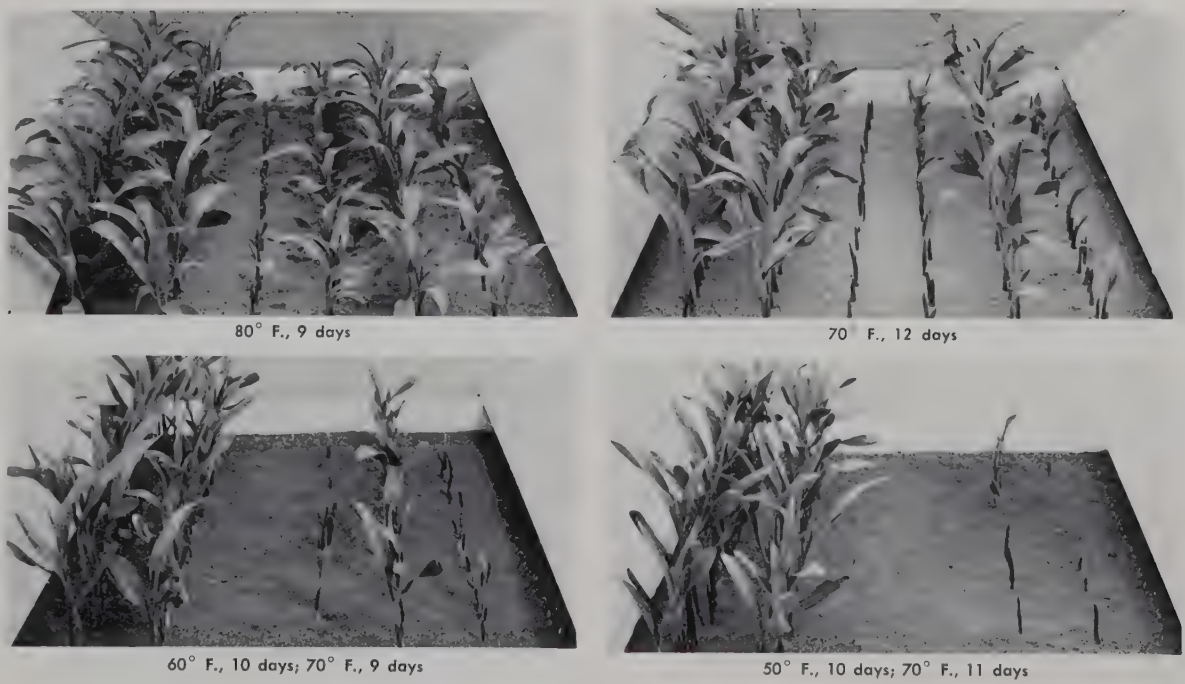
near the plumule reduced stand, but as shown previously, these plants had better vigor than plants from crown-injured seed. Results of the seed inoculation experiments are shown graphically in Fig. 11.

Penicillium oxalicum. It was discovered early in these studies (26) that the pathogenicity of this fungus is also greatly influenced by pericarp injuries. The pericarp injury technique has subsequently been used by other investigators working with *P. oxalicum* seedling blight in corn (5, 31). The above-ground symptoms from *P. oxalicum* blight vary with pericarp condition, the genetic constitution of the corn, and with the temperature. The symptoms have already been described quite well (5, 24, 31), but it is desired here to emphasize differences due to the pericarp condition of the seed. Symptoms and severity of the disease when the seed has been inoculated appear to be the same in natural soil as in disinfested sand. However, all data reported here are from experiments with disinfested sand.

Temperature. The effects of Penicillium inoculations at different temperatures varied widely, depending on the pericarp condition. At 70° to 80° F. when heavy spore loads were used, sound seed showed normal growth until the two-leaf stage or later. Then characteristic



Leaf blight caused by *Penicillium oxalicum* starting at the tip ends of young corn leaves. The dead area is blue-green at first, then turns drab or light brown. (Fig. 12)



Effect of temperature on growth of penicillium-inoculated seed. Plants grown from seed differing in pericarp condition, inoculated with *Penicillium oxalicum*. Row 1, sound check; 2, sound inoculated; 3, pericarp partially removed from the crown; 4, slight cut on one side of the plumule; 5, radicle exposed; 6, pericarp removed over horny endosperm at one edge of the kernel. (See also Table 15.) (Fig. 13)

Variations in vigor of plants from pericarp-injured seed. One plant shows only the pointed coleoptile. Others are in the one-, two-, and three-leaf stages. (Fig. 14)

symptoms of leaf blight began to show (Fig. 12): dead streaks or areas at the tips which are first dull blue-green in color, becoming dry and brittle, later turning tan or drab. When the pericarps were injured, vigor was affected more seriously than stand, especially at warm temperatures (Fig. 13). Soil moisture, within broad limits, appears to have little effect on the severity of blight caused by *Penicillium oxalicum* (5).

With the crown pericarp partially removed, at 70° to 80° F. many of the coleoptiles emerged normally but stopped growing after they were about 1 inch above the soil and remained closed (Figs. 13 and 14). Some plants developed several leaves and continued to grow, but were weak. Often the leaves of these plants were chlorotic at the start, soon drying at the tips and edges. Such seedlings finally died in an erect position. When the seed was kept at 50° F. for the first 10 days after planting, there was no emergence at all from seeds injured at the crown. Other types of pericarp injury had somewhat less severe effects at this temperature (Table 15, Fig. 13).

Thus stands from injured seed were best at 80° F. and the most damage from Penicillium blight occurred when the temperature was 50° F. during the first ten days after planting (Table 15). Johann *et al.* (24) reported the most damage from *P. oxalicum* seedling blight at 80° F. with reduced effects at lower temperatures. The writer also observed a tendency toward more leaf blight at the 3-leaf stage at 80°

than at 70° or 60° F. From the symptom descriptions, it appears that Johann was working primarily with sound seed; therefore the effects of increases in temperature were shown not in initial stand but as a postemergence loss from blight.

Spore concentration. P. oxalicum is remarkably effective at very low spore loads. Seed with four pericarp conditions was tested at widely different spore concentrations. The seed was planted in sterile

Table 15. — Effect of Temperature and Pericarp Condition on Stand, Growth, and Leaf Blight in Plants From Seed Inoculated With *Penicillium oxalicum*

(Hybrid U.S. 13, five pericarp conditions, inoculated with a spore suspension and planted in disinfested sand at four temperatures. After 10 days at 60° or 50° F. those in the cold chamber were placed in a greenhouse at 70°-75° F. until the three-leaf stage.)

Pericarp condition	Figure 13, row no.	80° F. 8 days	70° F. 12 days	60° F. 10 days	50° F. 10 days
Stand (angle)					
Crown injured	3	63	47	6	0
Injured near plumule	4	71	57	31	15
Injured over horny endosperm	6	84	65	57	27
Injured over radicle	5	87	76	55	33
Sound	2	90	87	87	85
Sound (check)[a]	1	90	90	90	87
L.S.D. (5-percent level)		7	7	7	7
Growth index[b]					
Crown injured	3	26	22	0.3	0
Injured near plumule	4	49	38	13	2
Injured over horny endosperm	6	55	45	26	6
Injured over radicle	5	92	78	45	14
Sound	2	97	94	89	88
Sound (check)[a]	1	98	98	99	98
L.S.D. (5-percent level)		5	5	5	5
Plants with one or more blighted leaves (percent)[c]					
Crown injured	3	14	12	..	..
Injured near plumule	4	33	13	15	17
Injured over horny endosperm	6	17	10	13	13
Injured over radicle	5	13	11	10	17
Sound	2	12	15	10	17
Sound (check)[a]	1	7	11	2	8
L.S.D. (5-percent level)		7	N.S.	7	7

[a] This seed was not inoculated and was treated with Arasan at the rate of 2 oz. per bu. However, some typical Penicillium leaf blight developed, infection coming from adjacent inoculated rows.

[b] Based on a value of 100 for a perfect stand of plants with 3 leaves (see page 11).

[c] Based on number of plants that emerged from the soil.

Table 16. — Effect of Spore Concentration on Stand, Plant Height, and Leaf Blight in Plants From Seed Inoculated with *Penicillium oxalicum*

(Hybrid U.S. 13 seed with various pericarp injuries made by hand, inoculated with various spore suspensions. Seed was planted in disinfested soil in 2-gallon cans, one inoculation and spore load to a can, and kept in a greenhouse at 70°-75° F.)

Spore concentration (Number of spores per ml. water)	Pericarp condition			
	Crown injury	Injury over horny endosperm	Tip cap broken off	Sound
Stand (angle)				
10,000,000	35.1	72.8	80.1	86.2
100,000	50.1	90.0	80.7	86.2
1,000	73.9	90.0	86.2	90.0
None (check)	86.2	90.0	90.0	90.0
L.S.D.	9.8	9.8	9.8	N.S.
Average height per plant (centimeters)				
10,000,000	1.8	5.3	16.4	17.5
100,000	1.8	8.7	16.1	17.5
1,000	2.3	11.6	16.6	17.7
None (check)	14.3	18.1	19.1	20.0
L.S.D.	1.5	1.5	1.5	1.5
Plants with one or more blighted leaves (percent)[a]				
10,000,000	13.0	37.5	16.0	.7
100,000	12.5	34.7	6.9	.7
1,000	16.7	15.3	1.4	0
None (check)	3.4	0	0	0

[a] Based on number of plants that emerged from the soil.

soil in 2-gallon cans, one seed condition and one spore load to a can. This was done to prevent the inoculum from spreading within the soil to the uninoculated rows, as in the previous experiment.

When the seed had pericarp injuries over the horny endosperm or the tip cap broken off, spore concentration was positively correlated with leaf blight (Table 16). Plant height was reduced at all concentrations for injury over the horny endosperm, but the effect became more severe at higher spore loads. With crown injury, stand varied according to spore concentration but plant heights were extremely poor at all concentrations. The data in Table 16 show an apparent decrease in blighted leaves at higher spore concentrations when the pericarp was injured at the crown. These percentages actually occurred because most shoots that emerged at high spore loads did not grow beyond the coleoptile stage, and thus did not develop any leaves.

Pythium debaryanum* and *Penicillium oxalicum gave quite similar results, but nevertheless there was an interaction between organism and pericarp condition. This relationship was significant at the 5-percent level for stands and at the 1-percent level for growth index and green weight per plant and per 100 seeds planted (Table 14). The discrepancy between parallel results from the two fungi occurred primarily among seed with slight crown injury. In that injury class *P. oxalicum* caused much greater damage than *P. debaryanum* (Fig. 11). Furthermore *P. oxalicum* was decidedly more damaging than *P. debaryanum* at warmer temperatures.

***Aspergillus flavus* and *A. tamarii*.** These two species of Aspergillus cause a virescent condition in seedlings, primarily when the pericarp is broken. The plants are similar in appearance to that of some inherited virescence types (Fig. 15). The ability of different isolates to cause this effect varied widely. Both of these Aspergilli differed markedly from Pythium and Penicillium isolates in their reaction to various types of pericarp injury. Virescence occurred almost as frequently when the seed was injured at the side of the kernel (only horny endosperm exposed) as when the seed was injured at the crown. Much

Virescence caused by Aspergillus flavus inoculations of seed with the crown pericarp injured. One healthy, and three virescent seedlings are shown. Much of the leaf area was nearly white except for green color at the leaf tips and some tendency toward green striping, as shown on the two plants at right. (Fig. 15)

less virescence occurred when the seed was injured at or near the plumule. On the other hand, seed injured at the plumule had considerably more damage from Pythium or Penicillium blight than those with only the horny endosperm exposed (Table 14). Other details about virescence induced by these Aspergilli have already been published (30).

Other fungi. Inoculation experiments with other fungi were only exploratory. Two pericarp conditions were used: sound and partially removed from the crown. Seed was planted in 2-gallon cans, using 3 replications and one inoculation to a can, and placed in a greenhouse at 70°-75° F. Nonsterile soil was used, as the interest at that time was primarily in natural field soil. The test was repeated in different soil the following year, with essentially the same results. Additional tests were made in which the soil moisture was adjusted to 40, 60, and 80 percent of the moisture-holding capacity.

Stands from the checks (noninoculated seed, sound and with the pericarp partially removed from the crown) were nearly 100 percent, but plants from injured seed were low in vigor, averaging only 72.5 percent the height of plants from sound seed. No doubt this difference in the vigor of the checks resulted from infestation by soil-borne fungi, probably Pythium.

Inoculated seed with the crown pericarp injured gave different results, depending on the fungus isolate used. These results can be divided into two classes:

No consistent effect different from that of the non-inoculated seed with crown injuries occurred when *Diplodia zeae, Gibberella zeae* (three isolates), *Aspergillus niger,* and *Trichoderma viride*[1] inoculations were made. This might indicate either that the fungus had no pathological effect under the conditions of these experiments, or that infestation by the pathogenic fungi naturally occurring in the soil was retarded and the inoculum itself caused seedling damage. One exception was *G. zeae* which reduced both stand and vigor at low soil moisture, compared with the check. This was also true of sound seed, although the difference was greater for injured seed. It has been reported that *G. zeae* inhibits certain Pythium spp. (9).

Vigor better than in check plants. Fusarium moniliforme (three isolates), *Penicillium notatum,* and *P. rugulosum* caused plants from injured seed to grow more vigorously than when it had not been inoculated. The vigor approached, but did not equal, that of plants from

[1] *T. lignorum* is considered a synonym according to Bisby (1).

sound seed. This seems to indicate that these fungi had an antagonistic or antibiotic effect on the pathogenic fungi in the soil. Edwards (7) had observed an antagonistic effect of *F. moniliforme* (*Gibberella fujikuroi*).

Excepting *Gibberella zeae* in dry soil, none of these organisms had any significant effect on stand or plant height from sound seed. Seed inoculations are often less effective than natural infection; results with *Diplodia zeae* and *G. zeae* are outstanding examples. Furthermore, the pathogenicity of isolates of some species varies widely. It seems probable, however, that pericarp injury did not greatly predispose the seed to seedling blight caused by the fungi mentioned, except *Penicillium oxalicum* and certain Pythium species.

EFFECTIVENESS OF SEED TREATMENT IN PROTECTING PERICARP-INJURED SEED AGAINST SEEDLING-BLIGHT INFECTION

Effects on stand and yield

Cold tests. An experiment was described previously (page 23) in which seed lots varying in the percentage of kernels with sound pericarps were given a cold test and the results measured in stand and green weight per 100 seeds planted (Table 7). Part of the seed was untreated and a duplicate sample was treated with Arasan at the rate of ¾ ounce per bushel. Both stand and green weight were improved with seed treatment, and doubled for the poorest seed. All stand increases from treatment were significant at the 1-percent level. On the other hand, stand and green weight varied with the pericarp condition almost as much with treated seed as with untreated, but the values for treated seed were higher throughout.

Field tests. When stands from commercially processed seed were compared with those from hand-handled seed in a three-year field experiment, seed treatment increased both stand and yield, but results from commercial seed with a great amount of pericarp injury were still lower than those from hand-handled seed. The three-year average given in Table 8 shows stands for untreated seed of 84.1 percent for commercial samples, 93.6 percent for hand-handled seed. With treatment, commercial seed produced a stand of 90.4 percent, hand-handled seed 94.4 percent. The acre yields without treatment were 87.1 and 96.9 bushels, and with treatment, 94.2 and 97.3 bushels, respectively. Average stands and yields from treated hand-handled seed with

the pericarp partially removed from the crown were almost exactly the same as those from treated commercially processed seed. When the pericarp was sound, seed treatment did not produce any significant increases in yield. The same results were obtained in another experiment (Table 17).

In fairly normal weather and conditions similar to normal farm practice, seed treatment gave about two-thirds control in stand and yield from seed with the crown pericarp injured, compared with results from hand-handled seed (Table 8). The differences in stand between treated commercial and hand-injured seed on one hand, and treated hand-handled (94-percent sound) seed on the other, were 4.0 and 3.3 percent respectively. These were significant at the 5-percent level. The corresponding differences in yield — 3.1 and 3.2 bushels — were not significant.

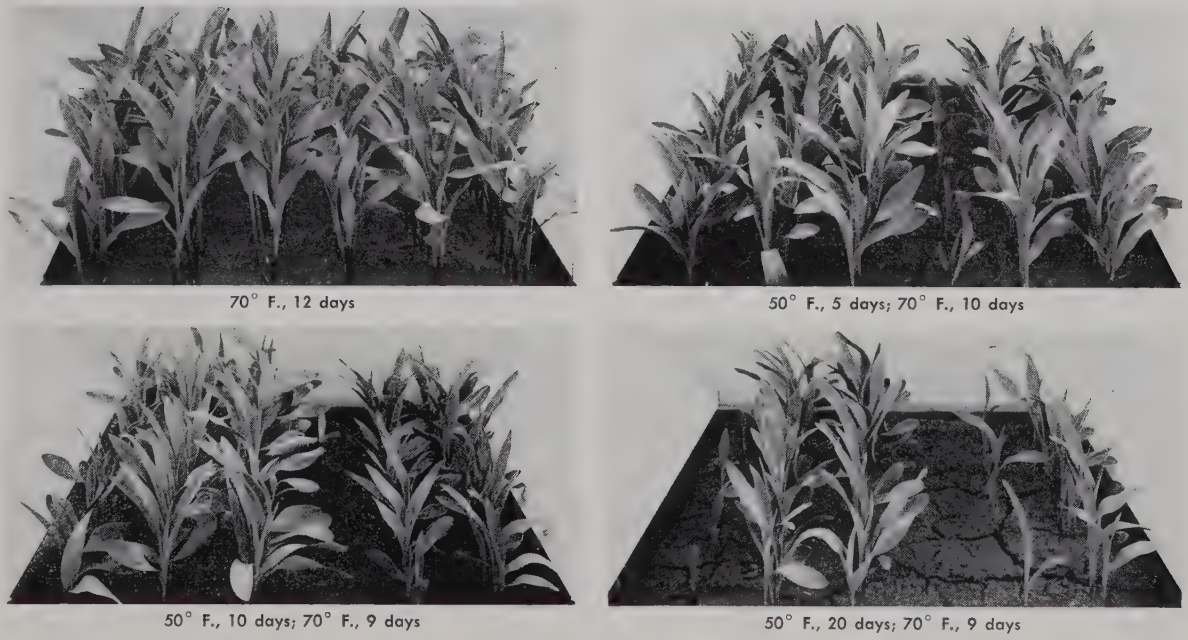
An average increase of 8.8 bushels per acre, or 10 percent, was obtained with Arasan treatment of commercially processed seed in field tests conducted from 1942 to 1955 at Urbana. The same degree of increase was noted in the results of the three-year-test shown in Table 8.

Under field conditions differences in vigor in the absence of differences in stand may or may not result in differences in yield. A case where increases in yield from seed treatment were found, even though treatment had not increased stand, has been reported (37, Table 4).

Importance of type of injury

In the annual tests conducted by the Illinois Station in 1954 and 1955 (Table 10) correlations were found between pericarp condition and stand and yield, in spite of the fact that all seed used in the tests had been treated with a protective fungicide before planting.

Another experiment was set up using seed from hand-handled ears prepared so that there were four pericarp conditions: plumule exposed, part of the crown pericarp removed, radicle exposed, and sound. Fig. 10, B and C, shows an exposed plumule and radicle. In this experiment, exposed plumule caused much greater damage to stand and yield than crown injury (Table 17). This was contrary to results from the cold tests with injured seed (Tables 13, 14, and 15), but in this test the cut was more severe, exposing the plumule visibly. Seed treatment caused significant increases in stand and yield when applied to pericarp-injured seed. Seed treatment at the rate of 1 ounce per bushel increased stands as follows: plumules exposed, 121; crown injured, 56; radicle exposed,



Effect of temperature and rate of seed treatment on seedling growth in naturally infested soil. Rows 1, 2, and 3 grown from sound seed; 4, 5, and 6 from seed with the pericarp partially removed from the crown. 1 and 4 were not treated; 2 and 5 were treated with ½ ounce Arasan per bushel, 3 and 6 with 2 ounces per bushel. (Fig. 16)

Table 17. — Effect of Seed Treatment on Stand and Yield From Pericarp-Injured Seed in Field Test, Urbana, 1944

(Hybrid Ill. 972-A1, part of the seed with pericarp injuries made with a knife and part of each group treated with Arasan, 1 ounce per bushel)

Pericarp condition	Field stand		Field stand		Acre yield	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
	perct.	*perct.*	*angle*	*angle*	*bu.*	*bu.*
Plumule exposed	20.2	44.7	26.0	41.2	37.2	67.6
Crown injured	58.7	91.5	49.2	71.6	62.4	94.5
Radicle exposed	73.9	93.4	58.4	73.7	89.0	96.6
Sound check	92.9	94.6	73.8	74.7	98.9	99.5
L.S.D. (5-percent level)			4.5	4.5	8.1	8.1

26; and sound pericarp, 6 percent. None of the increases for sound seed were significant. Stands and yields from seed with the plumule exposed were very poor despite the high percentage increases from seed treatment (Table 17). These results reinforce those obtained in the cold tests: seed with the pericarp injured at the crown or plumule is more susceptible to seedling blight than seed with the pericarp injured over the radicle. The results of this experiment emphasize that seed treatment often is effective only as a partial protection against seedling blight when the pericarp is damaged.

Effect of temperature

Stand and green weights. Sound and injured seed of U.S. 13 was treated with several rates of fungicide and grown at 70° F. and for three different periods at 50° F. in natural soil.

At 70° F., all stands were perfect (Table 18) and plants from all seed conditions appeared to be good (Fig. 16, top left), but there were some highly significant differences in green weights between plants from sound and plants from injured seed. This was true even when seed had been treated with 2 ounces of Arasan per bushel.

At 50° F. more important differences occurred, and interrelationships between pericarp condition and seed treatment became apparent. When the planted seeds were subjected to 50° F. for 10 or 20 days, there were significant differences in stand and green weight between the two rates of fungicidal treatment — ½ and 2 ounces per bushel — among injured seed (Table 18). With sound seed, significant differ-

Table 18. — Effect of Temperature and Rate of Seed Treatment on Stand and Green Weight From Pericarp-Injured Seed in Cold Tests

(Hybrid U.S. 13, treated with ½ or 2 ounces of Arasan SF-X per bushel and planted in naturally infested field soil. Seed was kept at 50° F. for the first 5, 10, or 20 days or at a constant temperature of 70° F.)

Pericarp condition	Seed treatment (oz. per bu.)	Figure 16, row no.	Days at 50° F.			
			0	5	10	20
	Stand (percent)					
Injured at crown	None	4	100	40	1	0
	½	5	100	99	81	22
	2	6	100	100	98	62
Sound	None	1	100	100	72	16
	½	2	100	100	99	83
	2	3	100	100	99	91
	Green weight (grams)[a]					
Injured at crown	None	4	44	10	0.3	0
	½	5	55	51	33	6
	2	6	59	52	45	25
Sound	None	1	63	58	35	3
	½	2	67	61	59	44
	2	3	67	63	62	51
L.S.D. (5-percent level)			6	6	6	6
L.S.D. (1-percent level)			8	8	8	8

[a] Green weight of plants from 100 seeds planted.

ences in stand were not noted until the cold period was 20 days. The average ranking for the various seed conditions was as follows:

1. Most severe damage — untreated, pericarp-injured seed.
2. Injured seed treated with ½ ounce Arasan almost same as sound seed untreated.
3. Injured treated with 2 ounces per bushel.
4. Sound seed treated. Treatment with 2 ounces gave better results than ½ ounce with seed subjected to 50° F. for 20 days.

Pythium infection. It has been shown that at 50° F. crown-injured seed treated with Arasan was protected from infection for 12 days or more (Table 11), whereas in untreated seed infection occurred in three days. However, after the roots were several inches long, the ends of the roots from treated and untreated seed were equally susceptible to Pythium invasion.

At 60° F., although infection reached 100 percent on the sixth day after planting in untreated, injured seed, there was very little infection in treated seed whether sound or injured.

Seed treatment was also partially effective against pre- and post-emergence blight of seedlings caused by *Penicillium oxalicum* in crown-injured seeds when this fungus occurred in the soil. Seed treatment did not, however, guard against leaf blight (Fig. 13) after plants were in the two- or three-leaf stage, regardless of the pericarp condition.

Effect of injury after treatment

Particularly in the planting process, pericarps may become injured after the seed has been treated. An experiment was conducted using two types of fungicidal treatment: a dust and a slurry. No sticker was added other than that contained in the SF-X formulation. Treatments were applied at three rates. The seed had been handled to insure, as far as possible, freedom from pericarp injuries except those artificially made by removing most of the crown surface. Some of the seed was injured before and some after applying the fungicide.

The most interesting result was that treatment provided considerable protection even when injuries were made in the pericarp after seed treatment. Stands were more than double those from untreated seed, although they were much lower than those from sound seed (Table 19). On the whole, an increase in the rate of application of

Table 19. — Effect of Pericarp Injury After Seed Treatment on Stands in Cold Tests From Seed Treated With Arasan at Three Rates

(Hybrid U.S. 13, untreated and treated with ½, 1, and 2 ounces Arasan per bushel. Seed was planted in naturally infested soil and kept at 50° F. the first 10 days.)

Seed treatment (oz. per bu.)	Pericarp condition	Stand (angle)		
		Not treated	Dust treatment[a]	Slurry treatment[b]
None	Injured	18	..	..
	Sound	68	..	..
½	Injured after treating	..	44	46
	Injured before treating	..	68	70
	Sound	..	85	83
1	Injured after treating	..	47	47
	Injured before treating	..	76	72
	Sound	..	90	85
2	Injured after treating	..	56	50
	Injured before treating	..	81	80
	Sound	..	84	90
L.S.D. (5-percent level)		8	8	7

[a] Arasan suitable for use as a dust treatment.
[b] Arasan SF-X.

fungicide gave somewhat better stands; some of the increases were significant. There were no significant differences in results between dust and slurry treatments.

EFFECT OF PERICARP CONDITION ON RESISTANCE TO SEEDLING BLIGHT IN CORN INBREDS AND SINGLE CROSSES

Resistance in inbreds

Eighteen inbreds with known reaction to Pythium (39) and Penicillium (31) seedling blight were selected on availability of a sufficient number of good ears produced under the same conditions. All were produced in the same field in the same year by the Plant Breeding Division, Agronomy Department, Illinois Agricultural Experiment Station. Kernels from each ear were first treated with sodium hypochlorite and then prepared by partially removing the pericarp from the crown of one group, making a slight cut alongside the plumule in others (Fig. 10, left), and leaving the third group sound. The seed was inoculated at planting time with a culture of *Pythium debaryanum* or *Penicillium oxalicum* or left uninoculated as checks and planted in formaldehyde-disinfested sand. Each replicate of 30 kernels consisted of a composite from five ears.

Results are expressed only as stands. In the checks, germination percentages of the composites were 95 to 100 percent (Table 20). Disease also affects vigor, but there was an inherent difference between inbreds in seedling vigor. The inbreds are ranked in Table 20 according to their average resistance to each disease for the three pericarp conditions. The averages were derived after the stands for each replication had been converted to angles. The ranking is slightly different when arranged according to the actual stand percentages (Fig. 17).

Effect of pericarp condition. The ranking of the inbreds varies considerably according to which pericarp condition is considered. Inbred R4 when inoculated with Pythium (Table 20) is a good example of nonconformity. Germination was perfect for seed with sound pericarps, but this inbred ranked among the poorest when the pericarp was injured either at the crown or near the plumule. B10 gave opposite results, ranking poorest of all in the sound pericarp classification but comparatively better when the pericarp was injured. R4, 38-11, and some other inbreds also showed considerable nonconformity in resistance to Penicillium seedling blight (Table 20). The nonconformities

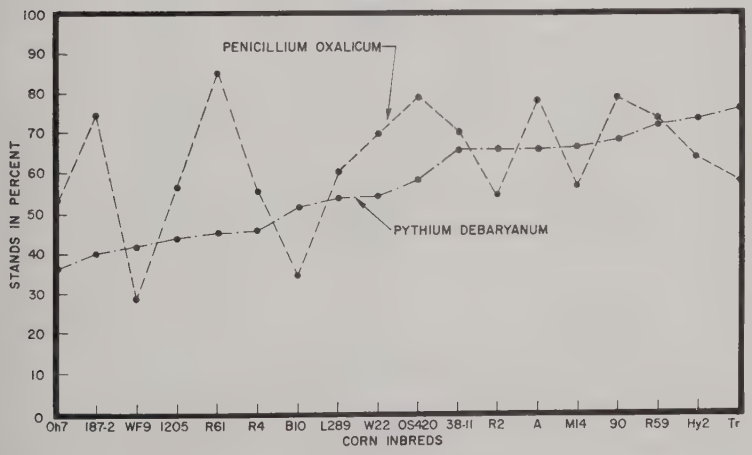
were highly significant as indicated by the triple interaction between pericarp condition, inbred, and pathogen used for inoculation.

Correlation of resistance between pericarp conditions. Considering all eighteen inbreds, there were some positive correlations between the results in stand for the various pericarp conditions for each pathogen in spite of the nonconformities, as follows:

	Pythium debaryanum	*Penicillium oxalicum*
Sound with crown injury	0.557*	0.616**
Sound with injury near plumule	0.563*	0.156
Sound with crown and germ injury (aver.)	0.595**	0.766**
Crown injury with injury near plumule	0.545*	0.104

* Significant at the 5-percent level.
** Significant at the 1-percent level.

The poor correlations between sound pericarps and injury near the plumule and between crown and plumule injury with Penicillium inoculations are due to the wide divergence of results for the different kinds of injury in a few inbreds, especially 38-11.



Relative resistance of 18 inbreds, shown by comparative stands obtained from seed inoculations with *Pythium debaryanum* and *Penicillium oxalicum.* Stands shown here represent the average values for three pericarp conditions: sound, injured near plumule, and partially removed from crown. The correlation (0.470) between the two values shown was significant at the 5-percent level. (Fig. 17)

Table 20. — Effect of Pericarp Condition on Resistance to Seedling Blight in Corn Inbreds as Shown by Stands From Inoculated Seed in Cold Tests

(Eighteen inbreds, seed inoculated with *Pythium debaryanum* and kept at 50° F. the first 7 days after planting or inoculated with *Penicillium oxalicum* and kept continuously in a greenhouse at 70°-75° F.[a])

Inbred	Stand					
	Sound check, not inoculated[a]		Pericarp condition of inoculated seed			Average, inoculated seed
			Sound	Crown-injured	Injured near plumule	
	perct.	*angle*	*angle*	*angle*	*angle*	*angle*
			Inoculated with *Pythium debaryanum*			
Oh7	100.0	90.0	56.8	6.5	37.8	33.7
187-2	100.0	90.0	62.8	6.5	39.2	36.2
WF9	95.0	77.1	56.8	25.5	37.0	39.8
R61	98.3	82.5	66.6	23.4	37.0	42.3
I.205	98.3	82.5	74.6	30.0	22.6	42.4
B10	96.7	79.5	56.1	33.2	48.7	46.0
R4	100.0	90.0	90.0	21.1	28.9	46.7
L289	100.0	90.0	74.6	33.9	38.4	49.0
W22	100.0	90.0	86.8	28.9	40.0	51.9
Os420	100.0	90.0	83.5	20.2	54.6	52.8
R2	100.0	90.0	80.8	34.7	57.7	57.7
A	98.3	82.5	83.5	33.0	57.6	58.1
M14	98.3	82.5	83.5	39.2	52.6	58.4
38-11	100.0	90.0	86.8	45.0	43.8	58.5
90	96.7	79.5	82.2	45.0	50.8	59.3
R59	100.0	90.0	90.0	50.9	49.3	63.4
Hy2	100.0	90.0	80.8	43.6	60.1	63.5
Tr	100.0	90.0	83.5	59.9	49.3	64.3
L.S.D. (5-percent level)			8.7	7.6	7.9	
			Inoculated with *Penicillium oxalicum*			
WF9	.....	....	49.5	8.4	29.6	29.2
B10	.....	....	57.0	24.0	23.2	34.7
Oh7	.....	....	79.6	43.1	24.7	41.1
R2	.....	....	76.8	41.9	31.4	50.0
I.205	.....	....	73.6	43.7	33.2	50.2
M14	.....	....	74.5	46.3	30.8	50.5
Tr	.....	....	74.5	55.5	25.6	51.9
R4	.....	....	86.7	27.3	42.5	52.1
L289	.....	....	80.5	42.5	36.5	53.2
Hy2	.....	....	90.0	58.5	26.3	58.3
W22	.....	....	90.0	43.7	53.1	62.2
187-2	.....	....	83.4	44.7	61.3	63.1
38-11	.....	....	90.0	25.9	74.8	63.6
R59	.....	....	90.0	40.9	64.3	65.1
A	.....	....	86.7	54.2	59.4	66.7
Os420	.....	....	86.7	70.2	45.8	67.6
90	.....	....	90.0	77.8	40.5	69.5
R61	.....	....	84.9	64.4	61.3	70.2
L.S.D. (5-percent level)			11.0	15.0	13.3	

[a] Seed used as check was treated with Arasan and kept at 50° F. 7 days after planting.

Correlation of resistance to two seedling diseases. When the pericarp was sound, there was a highly significant correlation (0.705) between resistance to seedling blight caused by Pythium and to that caused by Penicillium among the eighteen inbreds. The correlation was considerably lower (0.470) for the averages of all three pericarp conditions, but these were still significant at the 5-percent level. Correlations between resistance to the two diseases within either of the injured pericarp groups were not significant. Divergences in ranking of the inbreds' resistance to the two diseases due to differences in pericarp condition were highly significant.

The irregularity of R61 was most striking. This inbred showed the most resistance to Penicillium blight, but regardless of pericarp condition, it was well below average in resistance to Pythium (Fig. 17). R4 showed the most divergence between sound and injured pericarps for both diseases; it ranked at or near the top of all inbreds when sound, and among the lowest with any type of pericarp injury.

Resistance in single crosses

Six inbreds, differing widely in resistance were used in all possible combinations of single crosses. Sound seed and seed with crown-injured pericarps were planted in naturally infested soil. Reciprocal crosses were planted in the trays as paired rows. Sound seed was kept at 50° F. for 14 days, crown-injured seed for 5 days.

Different crosses produced widely different stands, but the two pericarp conditions for each cross gave quite similar stands. The correlation for stands between the two pericarp conditions for the thirty crosses was highly significant. But there was also a fairly consistent difference. The difference in stands between crosses with susceptible ear parents and those with resistant ear parents was generally greater when the pericarp was injured than when it was sound (Table 21).

Comparing average stands for each inbred when used as an ear parent (Table 21, last column) with stands for the inbreds (Table 21, second column), some similarity appears. Oh7, which ranked lowest when tested as an inbred, also averaged lowest in crosses in which it was used as an ear parent. WF9 and 187-2 ranked low, close to Oh7 as inbreds; they also ranked below average as ear parents, but well above Oh7. The resistant lines — Hy2, 90, and R59 — showed similar behavior when tested as inbreds, but R59 contributed much more resistance in the single crosses.

Influence of ear parent. A strong maternal influence on cold

Table 21. — Effect of Pericarp Condition on Resistance to Seedling Blight in Single Crosses as Shown by Stand in Cold Tests

(Single crosses made in all possible combinations from six inbreds differing widely in resistance. Seed was planted in naturally infested soil; sound seed was kept at 50° F. for 14 days, injured seed for 5 days, then placed in a greenhouse at 70°-75° F.)

Ear parent	Rating as an inbred (from Table 20)	Stand (angle)						
		Pollen parent						Average of hybrids with same ear parent
		Oh7	WF9	187–2	Hy2	90	R59	
Sound seed								
Oh7	56.8 (susceptible)	....	15.6	23.3	13.4	21.7	10.0	16.8
WF9	56.8 "	31.5	....	39.0	19.8	21.4	37.7	29.8
187–2	62.8 "	34.7	33.6	....	27.7	38.8	24.6	31.9
Hy2	80.8 (resistant)	16.4	28.2	45.3	....	45.6	40.1	35.1
90	82.2 "	33.1	29.8	39.7	34.1	....	50.0	37.3
R59	90.0 "	59.9	59.1	72.2	70.2	68.7	....	66.0
Average of hybrids with same pollen parent		35.1	33.3	43.9	33.0	39.2	32.5	....
L.S.D. (5-percent level) between crosses		7.6						
L.S.D. (5-percent level) between averages		3.9						
Seed with crown-pericarp injury								
Oh7	6.5 (susceptible)	....	7.7	21.3	11.3	16.2	10.0	13.3
WF9	25.5 "	23.2	....	32.4	22.6	22.1	22.7	24.6
187–2	6.5 "	25.3	15.6	....	27.4	26.4	16.3	22.4
Hy2	43.6 (resistant)	18.9	22.0	42.6	....	40.6	29.5	30.7
90	45.0 "	38.5	40.8	42.4	33.5	....	41.7	39.4
R59	50.9 "	76.3	54.8	64.4	71.8	68.3	....	67.1
Average of hybrids with same pollen parent		36.4	28.2	40.6	33.3	34.7	24.0	....
L.S.D. (5-percent level) between crosses		8.4						
L.S.D. (5-percent level) between averages		4.3						

test results has been reported in the literature (40, 43). This influence was also found in these experiments. When inbreds were used as ear parents, the average results were quite similar to those obtained from inbred testing. However, when these same inbreds were used as pollen parents there was no similiarity, and little average difference between crosses. This was true regardless of the condition of the pericarp. No doubt, this effect was due largely to the fact that the ear parent contributes twice as many chromosomes to the endosperm as the pollen parent. In addition, Hooker and Dickson found a disproportionate amount of maternal influence when the embryo is tested for susceptibility to *Pythium debaryanum* in the absence of the endosperm, but the effect was not great (15).

Influence of pollen parent. Although the influence of the pollen parent was much less pronounced than that of the ear parent on resistance, the pollen parent did have some significant effects. However, the effect was unpredictable from the reaction of the inbred. This was illustrated by the behavior of 187-2 which rated comparatively susceptible as an inbred but gave the highest average score for resistance when used as a pollen parent. Its superiority was significant at the 5-percent level. Oh7, the most susceptible inbred, when used as a pollen parent gave results as good as those rated resistant. Pinnell (40) obtained similar results with eight entirely different inbreds; an inbred rated as good in the cold test and one rated as poor gave exactly opposite results when used as pollen parents in crosses. However, these were exceptions to the rule.

Hy2, 90, and R59 were rated as comparatively resistant to *Pythium debaryanum,* as inbreds. When tested in single crosses, R59 as an ear parent was much superior to the others, but when used as a pollen parent this inbred contributed the least resistance of all six (Table 21).

These results indicate a very complex genetic situation and probably cannot be explained by any simple heritable relationship.

CONTROL OF SEEDLING BLIGHT IN DENT CORN

The prevention of losses in stand and yield from seedling blight disease enhanced by pericarp injuries in the seed can be approached from three directions: avoidance of pericarp injuries, seed treatment, and genetic resistance and combining ability. Attention to all three is essential, since pericarp injuries cannot be altogether eliminated, and neither of the other possible means of control is completely effective.

Other seed conditions affecting the development of seedling blight are maturity (28, 41), age (28, 41), environmental conditions during the growing season (14), and the presence of certain fungi on or within the seed (29).

Avoidance of pericarp injuries

Immature seed is more subject to pericarp damage. As the results of these experiments show, immature seed is much more susceptible to spontaneous cracking of the pericarp during the drying process than mature seed. When subjected to a mechanical hazard, such as dropping on a stone floor, even moderately immature seed is subject to more pericarp damage than mature seed. Wright (47) has suggested that harvesting be delayed until the moisture content is between 27 and 30 percent.

Shelling at moistures above 12 percent was damaging. The detrimental effect of shelling at high grain moistures has been reported here. Damage to seed increases as moisture at shelling rises above 12 percent, and is also higher at lower moistures. Moisture in the cob, as well as in the seed, should be considered to avoid tip-cap damage. By allowing drying bins to cool a day before shelling, seed and cob moistures can be equalized and tip damage prevented (47).

Some of the pericarp injury in commercial seed could be avoided by careful handling. In the samples examined, commercial seed averaged only about 22 percent sound kernels. Since considerable variations in the prevalence of pericarp injuries were noted between samples from different producers, it seems possible that much improvement can be made in methods of handling and processing seed.

Methods and equipment need to be adjusted. In his excellent discussion on avoiding pericarp damage, Wright (47) stressed the point that much of the commercial equipment now in use has been designed for feed corn, and new equipment and methods will be required to reduce pericarp damage to seed corn. Progress is being made in this direction by some manufacturers. Seed processors have improved seed quality by operating shellers and conveyors at much lower speeds than the manufacturers recommend. Other improvements can be made by altering present machinery and methods. Some of his suggestions were:

Remove pegs from the snapping rolls of corn pickers and replace the husking rolls with rubber ones..

Avoid picking too clean and rely on removing husks before the corn enters the drying bins.

Use rubber elbows in conveyor pipes through which seed flows by gravity; forced-air conveying can be very damaging to the seed. Also, rubber conveyor belts, rubber buckets, or rubber flights can be helpful.

Cylinder graders cause more damage than flat-screened vibrator types.

Cylinder shellers for seed corn should have lugs well-worn by use on feed corn, or dressed to the shape of smooth, well-rounded knobs.

Cushion the fall of ear and shelled corn with canvas chutes and rubber padding. Chutes that are too steep are damaging; spiral and zig-zag arrangements help to slow the speed of descent.

Cup elevators produce less damage if fed at the bottom of the down-leg side. Speed should be slow, but additional cups may be added to maintain capacity. Discharge the seed on an abrasion rubber pad.

Vibrator feeders, either magnetic or mechanical, help by providing a constant flow to elevators and processing machinery; they can readily be adjusted to various speeds.

A systematic check can locate the source of damage. Most processing plants have developed their own systems of operation and handling; thus no uniform recommendations for reducing pericarp damage can be given. A good way of finding out where the trouble spots in the process are, is by staining a sample of seed and making a systematic check after each operation. Then adjustments such as those suggested above can be made to cut down damage in the more important sources.

Seed treatment

Seed treatment prevents much of the loss from seedling blight, but has not yet been developed to give complete control. Treating seed with a recommended fungicide at an adequate rate will give about two-thirds control over losses in yield that might result with untreated seed having a great amount of pericarp injury. Most processing plants have adopted this practice.

Resistance in inbreds and crosses

Resistant inbreds or single crosses have greater influence when used as ear parents. The present use of a certain inbred in a cross is determined almost entirely on characters other than seedling blight resistance. Although results of these tests show that resistance of certain lines may differ with various pericarp conditions, it is generally an

advantage to use the most resistant inbred or single cross as an ear parent, because the ear parent has a larger influence on the susceptibility of the resulting cross to seedling blight.

A cold test can be used to determine relative resistance. Considerable differences in resistance have been shown between inbreds as well as between crosses (Table 21). If a producer wishes to determine the resistance of his inbreds or crosses, he can do so with a cold test of his own seed, the simplest method being the one described by Hoppe (19). The samples tested should each involve a number of ears of the same pedigree; all inbreds or hybrids being compared should have been produced in the same year under the same conditions (13, 14, 40). It does not appear to make much difference whether the pericarps are sound or injured, but they should be alike. Because it is so difficult to assure sound pericarps, even with careful handling, it would be advisable to injure all the seed at the crown before testing.

DISCUSSION

Examinations of many samples of commercial seed corn made in each of ten years showed considerable variation from year to year in the amount and kinds of pericarp injury, but during the thirteen-year period there was no apparent trend toward improvement. The data indicate that (a) samples from some seed processors average considerably less injury than those from others; (b) samples from one processor may be higher than average in one type of pericarp injury while those from a different processor may be higher than average in a different type; (c) samples of the same hybrid obtained from different processors may vary greatly in the amount of injury; and (d) samples of different hybrids from the same processor may vary considerably. There may be differences between samples of the same hybrids from one processor, if they are obtained from different fields, but this has not been investigated.

At least four factors appear to be responsible for the differences between samples in the prevalence of pericarp injury: moisture content of the grain when harvested, handled, and processed; maturity of the seed, genetic nature of the seed, and type of mechanical handling and manipulation. All of these are somewhat under the control of the seed producer and processor and no doubt improvements can be made in many cases.

Shelling at high moisture increased pericarp damage greatly. Doubtless no one would shell seed corn at the maximum moistures used in these experiments, but since similar results were obtained with two

shellers operating on different principles, a similar effect, although probably less acute, might be expected in other mechanical manipulations. In samples obtained from a commercial processing plant, Wortman and Rinke (46) found that the sheller was the most important single cause of pericarp injuries. Harvesting experiments with a picker-sheller (3) and a grain combine (16) have demonstrated a great increase in kernel damage with increases in grain moisture.

Not much experimental data are available on the effect of maturity on the susceptibility of seed corn to pericarp damage. In some earlier work the writer found a considerable increase in pericarp injury in immature seed compared with mature seed after hand-handled ears had been dried (28). These injuries occurred primarily on the part of the kernel nearest the cob. In the experiment reported in this bulletin this effect occurred again to a significant extent. In some other immature seed samples, a considerable amount of blistering was observed. Immature kernels are also more subject to injury from mechanical hazards than mature seed. Wortman and Rinke (46) reported this observation in mechanically processed seed; the same conclusion was reached from an experiment reported here (Table 4). Immature seed was more subject to injury when it had been dropped 15 feet onto a smooth stone floor. Differences between mature and immature seed in susceptibility to this type of damage may be even greater than the data show, since the immature seed is lower in specific gravity and less smooth than mature seed and therefore probably attains less velocity in falling.

Corn and flax are two crops known to be especially susceptible to seedling blight when the pericarp is broken and not protected by a fungicide. If seed could easily be produced free from pericarp injury, seed treatment could probably be recommended only for certain special conditions.

A very surprising result in a cold test was the superior performance of carefully hand-picked and hand-handled seed compared with that of seed selected as sound from commercial samples obtained from the same seed-producing field. The cause of the difference was not ascertained. Three apparent differences in preparation of the seed occurred: in drying methods; subjection to shock, which was considerable in mechanical shelling but carefully avoided with the hand-picked seed; and selection — hand-picked ears were limited to those that were fully developed and free from molds and injuries.

Better stands were obtained from pericarp-injured seed in the cold tests when the period at low temperature was delayed for several

days after planting. The effects of disease damage decreased, and the differences between resistant and susceptible hybrids were minimized whether results from sound or pericarp-injured seed are considered (Table 12). It has been observed by the writer that in the field, the onset of unfavorable temperatures several days after planting is less detrimental to stand and the effect of fungicidal treatment less pronounced than when they begin earlier. These results agree partially with those reported by Hooker and Dickson (15): that resistance to seedling blight may build up fairly rapidly under conditions favorable for germination. This effect could probably have been counteracted by following the initial warm period by a longer period of time at low temperature.

Several investigators have recognized that not all kinds of pericarp injuries are equally important, and each has devised a system of classification. Wortman and Rinke (46) found that chips broken off are responsible for more serious damage to seedlings than a small crack in the pericarp. This agrees with results reported here which show that removal of one-fourth or more of the crown pericarp allowed more disease damage in cold tests than less extensive injuries at the crown. Injuries on the face of the germ were divided into two classes, since early in this work (23) it was observed that injuries over the plumule are much more important than those over the radicle.

In commercial seed when one-fourth or more of the crown pericarp was missing, the effect on stand was more severe than the average for injuries over or near the plumule (Table 9). Injury at the crown often involves a much larger area than injuries at or near the plumule. Compared with the average injuries — ranging from slight cracks up to nearly one-fourth of the crown — injury over the plumule usually was the most important with respect to stands. This was also generally true for hand-made injuries. An exception occurred in a field test (Table 17), where exposure of the plumule caused much more damage to stand and yield than removal of most of the crown pericarp. However, in this experiment a small piece of pericarp was actually removed from the germ area, visibly exposing the end of the plumule. Tatum and Zuber (44) reported a similar effect in a cold test, and Livingston (33) found that peeling a strip of pericarp from the germ area had a more detrimental effect than peeling a similar strip of pericarp from the crown. There seems to be general agreement that when the pericarp injuries are of similar kind or magnitude, the effect on stand is most severe when the injury occurs at or near the plumule.

A curious fact, not mentioned by others, is that regardless of

stand plants produced by crown-damaged seed were much lower in vigor than plants produced by seed with injuries over the plumule (Tables 9, 14). This was true regardless of the extent of crown damage, whether the injury occurred in processing or was artificially made, and whether the blight was caused by *Pythium debaryanum* or *Penicillium oxalicum*.

Several species of Pythium and *Penicillium oxalicum* are the only organisms now known to be very greatly influenced in their capacity to cause severe seedling blight by the pericarp condition of the seed. Pythium species occur almost universally in cultivated soil, but apparently their kinds, abundance, and virulence vary. *P. oxalicum*, fortunately, does not occur very extensively in soil; when the seed pericarp is injured, this pathogen is very damaging in minute amounts. Natural Penicillium seedling blight occurring in farm practice appears to result more frequently from seed-borne than from soil-borne infestation.

When seed with sound pericarps was planted in naturally infested soil and kept at 50°, 60°, or 70° F., no Pythium infection took place until one to several days after the pericarp had broken due to growth processes (Table 11). Infection was still further delayed and diminished when the seed had been treated with a protective fungicide. On the other hand, when the pericarp had been physically damaged, and seed not treated, fungi penetrated the pericarp almost immediately after planting.

In testing the effects of pericarp injuries on seedling-blight development at low temperature, some investigators treated the seed with a protective fungicide. Similar gradients were obtained in parallel tests made by the writer with and without seed treatment, but the stands were considerably higher throughout for treated seed (Table 7). The tests can be adjusted to obtain similar stands by exposing treated seed to a longer cold period. For example, a 40-percent stand from seed with the crown pericarp partially removed was obtained in five days at 50° F.; a similar stand could be obtained from the same type of seed treated with Arasan, ½ ounce per bushel, by extending the cold period to 10 to 20 days (Table 18). The same principle can be applied in testing different rates of fungicidal treatment on seed of the same pericarp condition: in a five-day cold test, ½ ounce and 2 ounces of Arasan per bushel gave equal control with crown-injured seed, but in a ten-day test, the 2-ounce rate was significantly better.

When testing different kinds of corn for resistance to seedling blight, in most cases it does not appear to be of very great importance whether the pericarps are sound or injured. What is most important

is that they be alike for all entries being compared. Furthermore, it should not be assumed that they are alike just because no pericarp injuries have been made intentionally. Resistance is only relative. The most resistant line, with a considerable part of the crown pericarp removed from all kernels, can be expected to rank similar to the most susceptible line with all pericarps sound when tested under the same conditions. Unless exceptional care has been used in handling to assure sound pericarps, it would seem best to injure all the seed at the crown before testing. Injuries at the crown are made more quickly than those over the plumule and in practice have also resulted in less variability in results. Further, in commercial use, injured pericarps are more common than sound, some inbreds rank quite differently when the pericarps are injured, and a test of seed with injured pericarps requires less time at low temperature.

Some preliminary experimentation is required to determine the desired time of exposure to low temperature in a cold test. The disease effect obtained is influenced by the infective potential of the soil, the nature of the seed being tested, soil moisture, and other factors. If the time at low temperature is too short, for example, an inbred of intermediate susceptibility may produce a full stand and appear to be as good as the most resistant line tested. If the test is too severe, only the most resistant entries will produce any stand, and the others will appear to be equally susceptible. In some cases, of course, it is desired only to detect the most resistant lines.

In the production of crosses, the susceptibility to Pythium seedling blight depends largely on the susceptibility of the ear parent, regardless of whether it is an inbred or single cross. In single crosses an inbred with known resistance to Pythium seedling blight should be used as the ear parent unless there are other reasons to prevent it. However, the susceptibility of F_1 seed to seedling blight was also influenced to some extent by the pollinator. The tests of single crosses reported here were very limited in number, but the data indicate that while the effect of the pollen parent is appreciable, the result cannot be predicted from its resistance rating as an inbred. The actual comparative resistance of hybrid seed of any genetic composition must be determined by test, because of differences in combining ability. Results may also differ between seed lots due to the environment during the growing season and other factors. Inbreds that have been grown by different seed producers for some years have been found to differ considerably in their resistance to seedling blight.

SUMMARY

Samples of commercial seed corn were found to vary considerably in the amounts and kinds of pericarp injury. Many seed samples of commercial hybrids were examined in each of ten years over a thirteen-year period. A staining technique, adapted in 1951, enabled many pericarp cracks to be detected that could not be seen otherwise. After staining, commercial seed was found to average only about 22 percent sound kernels. There was no apparent trend toward a reduction in pericarp injury during the period.

Shelling at high moisture increased pericarp damage. The amount of injury increased rapidly as the grain moisture content rose above 12 percent to 29 or 34 percent, and there was a tendency for damage to increase at moistures below 12 percent.

Immature seed was more subject to pericarp damage than mature seed. Very immature seed had a higher incidence of spontaneous pericarp cracking during the drying process, and when seed was subjected to identical mechanical hazard by dropping 15 feet onto a stone floor, even slightly immature seed showed more susceptibility to injury than mature seed. In this test, three hybrids differed significantly in the amount of pericarp injury caused by an identical mechanical hazard.

Pericarp injury also appeared to be influenced somewhat by grade size; there was a tendency for damaged kernels to increase as grade size increased. Damage tended to occur more frequently in the "rounds" than in the "flats."

Better stands were obtained from carefully handled hand-picked seed than from sound kernels selected from commercially processed seed. Severe crown injuries had the most serious effect on stand. The different types of pericarp injury ranked as follows in the severity of their effect on stand: severe crown injury, injury over or near the plumule, slight crown injury, injury at margin of germ area, other pericarp injuries, injury over the radicle, and tip cap broken off.

Vigor of plants was affected more severely by crown injuries, whether severe or slight, than by injury over the plumule with seedling blight caused by either *Pythium debaryanum* or *Penicillium oxalicum*. When different rates of planting were used in a field test, it was determined that acre yields from crown-injured and sound seed differed significantly even when stands were the same.

The prevalence of each type of pericarp injury was correlated negatively with stand and yield in field tests, although the seed had been treated with a fungicide. Thirty-six samples of commercial seed corn used in the 1954 and 1955 hybrid corn tests made by the Illinois

Station were examined for pericarp injuries. Highly significant correlations between stand and yield were noted in both tests, and the percent of sound kernels per sample was positively correlated with stand and yield. Some of these relationships were highly significant. This sort of correlation is likely to occur only under conditions especially conducive to seedling blight.

Striped plants were observed in field plantings in two different years; they occurred only when the seed had pericarp injuries, and it was shown that this striping was not heritable.

High soil moisture improved growth in plants from sound seed, but increased disease damage to pericarp-injured seed. When experiments were conducted with naturally infested soil adjusted to three levels of moisture content, only stands from injured seed decreased at higher moistures. The green weight of plants from sound seed improved at higher soil moistures.

Exposure to cold temperature immediately after planting had the most severe effect on stand from pericarp-injured seed. When the cold period was delayed for several days, improved stands were obtained from injured seed, and the differences in stand between susceptible and resistant hybrids, as well as sound and injured seed were reduced.

Pythium species were the first invaders of seed planted in moist field soil. Of those species identified, *Pythium debaryanum* appeared to occur most frequently. Sound seed was fully protected against invasion until after the pericarp had split open due to growth. In seed with pericarp injuries, invasion occurred much earlier.

Pythium debaryanum and *Penicillium oxalicum* were the only organisms found in seed inoculation tests to be greatly influenced by the pericarp condition of the seed in their ability to cause seedling blight. Results with these two organisms, regarding the degree of disease damage caused with seed differing in pericarp condition, were somewhat similar. The main difference was that *P. oxalicum* was more active in the slight crown injury class. This pathogen was found to be very damaging even at very low spore concentrations.

Aspergillus flavus and *A. tamarii* in inoculation experiments caused virescence rather than seedling blight. The effect was most pronounced with injury at the crown or at the side of the kernel, and not as noticeable with injuries on the face of the germ.

Considerable increases in stand and yield were obtained by the use of seed-treating fungicides. Yield data show that treatment of commercial seed averaging only about 19 percent sound kernels gave about two-thirds control over seedling blight, compared with yields from

hand-picked, hand-handled seed that had a low incidence of pericarp injuries. When crown injuries were made after the seed had been treated, treatment was about half as effective. Seed treatment did not control Pythium rot at the end of seminal roots, nor was it effective against *Penicillium oxalicum* leaf blight in infested soil after seedlings had reached the two- or three-leaf stage.

In field tests with sound and injured seed in four different years, seed treatment gave no significant increases in yield where the pericarp was sound. But over fourteen years, in tests with commercially processed seed, an average increase of 8.8 bushels per acre, or 10 percent, was obtained with the use of Arasan.

The ranking of inbreds according to their resistance to seedling blight was affected by the pericarp condition of the seed as well as by the pathogen. Eighteen inbreds were tested for resistance to *Pythium debaryanum* and *Penicillium oxalicum*, and three pericarp conditions were used. In general, there were some significant relationships between the pericarp conditions and the ratings of the inbreds in resistance to each fungus, as well as their relative resistance to the two diseases. But some inbreds ranked very differently for different pericarp conditions, while others ranked differently in resistance to the two diseases. These differences were significant as tested by the interaction between inbred, pericarp condition, and pathogen.

In tests of single crosses involving six inbreds — three susceptible and three resistant to *Pythium debaryanum* — a strong maternal influence was found on resistance to seedling blight. Crosses made up with susceptible inbreds as ear parents averaged more susceptible to Pythium seedling blight than those with comparatively resistant ones. There was also a significant paternal influence on resistance, but the effect could not be predicted from the inbred rating. Some susceptible inbreds used as pollen parents gave a better average for resistance than some resistant inbreds. These relationships were the same regardless of whether seed with sound or crown-injured pericarps was used.

Control of seedling-blight damage enhanced by pericarp injuries in the seed can be approached in three ways: new methods and adjustment of equipment used in processing seed can help to reduce the high incidence of pericarp injuries; seed treatment with a good fungicide at an effective rate can produce better stands and yields from seed with a great amount of injury than could be expected without protection; and the use of resistant inbreds and single crosses as ear parents, while subject to other factors, is probably the most effective way to obtain resistance to blight, regardless of the seed-pericarp condition.

LITERATURE CITED

1. BISBY, G. R. *Tricoderma viride* Pers. ex. Fries and notes on Hypocrea. Trans. Brit. Mycol. Soc. **23**:149-168. 1939.
2. BROWN, E. B. Relative yields from broken and entire kernels of seed corn. Amer. Soc. Agron. Jour. **12**:196-197. 1920.
3. BURROUGH, D. E., and HARBAGE, R. P. Performance of a corn picker-sheller. Agr. Engin. **34**:21-22. 1953.
4. CUNNINGHAM, C. C. Relation of ear characters of corn to yield. Amer. Soc. Agron. Jour. **8**:188-196. 1916.
5. DIACHUN, STEPHEN. The effect of some soil factors on penicillium injury of corn seedlings. Phytopathology **29**:231-241. 1939.
6. EDGERTON, C. W., and KIDDER, A. F. Fungous infection of seed corn kernels and the importance of germination tests. La. Agr. Exp. Sta. Bul. 193. 24p. 1925.
7. EDWARDS, E. T. The biological antagonism of *Gibberella fujikuroi* and *Gibberella fujikuroi* var. subglutinans to *Trichoderma viride*. Austral. Inst. Agr. Sci. Jour. **6**:91-100. 1940.
8. FLOR, H. H. Relation of environmental factors to growth and pathogenicity of Pythium isolated from roots of sugar cane. Phytopathology **20**:319-328. 1930.
9. HALTIWANGER, W. L., and WERNHAM, C. C. Some fundamental studies on cold testing of corn. (Abs.) Phytopathology **42**:467. 1952.
10. HO, WEN-CHUN. Soil-inhabiting fungi attacking the roots of maize. Iowa Agr. Exp. Sta. Res. Bul. 332. 46p. 1944.
11. HOLBERT, J. R., BURLISON, W. L., KOEHLER, BENJAMIN, WOODWORTH, C. M., and DUNGAN, G. H. Corn root, stalk, and ear rot diseases and their control thru seed selection and breeding. Ill. Agr. Exp. Sta. Bul. 255. 244p. 1924.
12. HOOKER, A. L. Severity of corn seedling disease in Iowa soils. Iowa Acad. Sci. **60**:158-162. 1953.
13. ———— Intra-inbred line variation in resistance to a pythium seedling disease of corn. Agron. Jour. **47**:580-582. 1955.
14. ———— Additional seed factors affecting stands of corn in cold soil. Agron. Jour. **47**:582-585. 1955.
15. HOOKER, A. L., and DICKSON, J. G. Resistance to Pythium manifest by excised corn embryos at low temperatures. Agron. Jour. **44**:443-447. 1952.
16. HOPKINS, D. F., and PICKARD, G. E. Corn shelling with a combine cylinder. Agr. Engin. **34**:461-464. 1953.
17. HOPPE, P. E. Differences in pythium injury to corn seedlings at high and low soil temperatures. Phytopathology **39**:77-84. 1949.
18. ———— A new technique for incubating seed corn in cold soil for disease tests. Phytopathology **41**:747-751. 1951.
19. ———— Cold testing seed corn by the rolled towel method. Wis. Agr. Exp. Sta. Bul. 507. 56p. 1955.
20. HOPPE, P. E., and MIDDLETON, J. T. Pathogenicity and occurrence in Wisconsin soils of Pythium species which cause seedling disease in corn. Phytopathology **40**:13. 1950.
21. HUELSEN, W. A., and BROWN, W. N. Physical damage to sweet corn caused by mechanical harvesting and subsequent processing. Ill. Agr. Exp. Sta. Bul. 561. 48p. 1952.

22. Illinois Agricultural Experiment Station. Smooth corn less susceptible to harmful seed-coat injury. 48th Ann. Rpt.:46-47. 1936.

23. ———— Corn seed-coat injuries increase seedling blight. Nine-year Rpt.:28-29. 1948.

24. JOHANN, HELEN, HOLBERT, J. R., and DICKSON, J. G. Further studies on penicillium injury to corn. Jour. Agr. Res. **43**:757-790. 1931.

25. JONES, L. R., JOHNSON, J., and DICKSON, J. G. Wisconsin studies upon the relation of soil temperature to plant disease. Wis. Agr. Exp. Sta. Res. Bul. 71. 144p. 1926.

26. KOEHLER, BENJAMIN. Pathologic significance of seed coat injury in dent corn. Phytopathology **25**:24. 1935.

27. ———— Effect of seed coat injury on germination, vigor, and yield of corn. Trans. Ill. State Acad. Sci. **28**:52-54. 1935.

28. ———— Some conditions influencing the results from corn seed treatment tests. Phytopathology **44**:575-583. 1954.

29. KOEHLER, BENJAMIN, and HOLBERT, J. R. Corn diseases in Illinois. Ill. Agr. Exp. Sta. Bul. 354. 164p. 1930.

30. KOEHLER, BENJAMIN, and WOODWORTH, C. M. Corn-seedling virescence caused by *Aspergillus flavus* and *A. tamarii*. Phytopathology **28**:811-823. 1938.

31. LENG, E. R. Differential reaction to penicillium seedling disease of corn. Agron. Jour. **41**:435-439. 1949.

32. LENG, E. R., and KOEHLER, BENJAMIN. 1955 Illinois corn tests. Ill. Agr. Exp. Sta. Bul. 598. 32p. 1956.

33. LIVINGSTON, J. E. Injury and drying of seed corn in relation to emergence. Phytopathology **42**:221-222. 1952.

34. MANNS, T. F., and ADAMS, J. F. Corn root rot diseases. Del. Agr. Exp. Sta. Bul. 128. 24p. 1921.

35. MEYERS, M. T. The influence of broken pericarp on the germination and yield of corn. Amer. Soc. Agron. Jour. **16**:540-550. 1924.

36. MONTGOMERY, E. G. Experiments with corn. Neb. Agr. Exp. Sta. Bul. 112. 36p. 1909.

37. PENDLETON, J. W., KOEHLER, BENJAMIN, LANG, A. L., JOHNSON, P. E., and BIGGER, J. H. 1953 Illinois corn tests. Ill. Agr. Exp. Sta. Bul. 571. 32p. 1954.

38. ———— 1954 Illinois corn tests. Ill. Agr. Exp. Sta. Bul. 585. 32p. 1955.

39. PFEIFER, R. P. Differential reactions of inbred lines and hybrids of corn to certain seed disinfectants. Unpublished doctoral thesis, 76p. 1949. (Available at the University of Illinois Library)

40. PINNELL, E. L. Genetic and environmental factors affecting corn seed germination at low temperatures. Agron. Jour. **41**:562-568. 1949.

41. RUSH, G. E., and NEAL, N. P. The effect of maturity and other factors on stands of corn at low temperatures. Agron. Jour. **43**:112-116. 1951.

42. SPRAGUE, RODERICK. Diseases of cereals and grasses in North America. The Ronald Press, New York. 1950.

43. TATUM, L. A. The effect of genetic constitution and processing methods on the ability of maize seed to germinate in cold soil. Iowa State Col. Jour. Sci. **17**:138-140. 1942.

44. TATUM, L. A., and ZUBER, M. S. Germination of maize under adverse conditions. Agron. Jour. **35**:48-59. 1943.

45. WERNHAM, C. C. Cold testing of corn, a chronological and critical review. Pa. Agr. Exp. Sta. Prog. Rpt. 47. 12p. 1951.

46. WORTMAN, L. S. and RINKE, E. H. Seed corn injury at various stages of processing and its effect upon cold test performance. Agron. Jour. **43**:299-305. 1951.

47. WRIGHT, HAROLD. Processing seed corn to avoid injury. *In* What's New in the Production, Storage and Utilization of Hybrid Seed Corn. Amer. Seed Trade Assoc. Proc.:32-37. 1948.

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